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Mercury Walch, Hobart, Tasmania

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA

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SANITARY FORUM: THE ROYAL SOCIETY OF TASMANIA AND PUBLIC HEALTH REFORM 1853–1911

by Stefan Petrow

Petrow, S. 2013 (17:xii): Sanitary forum: The Royal Society of Tasmania and public health reform 1853–1911. *Papers and Proceedings of the Royal Society of Tasmania* 147: 1–10. Department of History and Classics, School of Humanities, University of Tasmania, Private Bag 41, Hobart Tasmania 7001, Australia. Email: Stefan.Petrow@utas.edu.au

In the nineteenth century Tasmania experienced a number of epidemic diseases like scarlet fever, diphtheria and, most deadly of all, typhoid. Sanitary reformers attributed the epidemics to contaminated water supplies, accumulations of decomposed rubbish, poorly built houses and the absence of underground drainage schemes. Leading reformers, most notably Dr Edward Swarbreck Hall, were Fellows of The Royal Society of Tasmania and used the society as a forum to identify the causes of epidemic disease and to explain the public health reforms that would prevent death and illness. Lectures and papers by medical doctors, sanitary engineers, and statisticians drew on the latest thinking in sanitary science and helped build momentum for public support of such reforms. This paper examines the arguments of sanitary reformers and the reaction to their interventions and concludes that between 1853 and 1911 the Royal Society was the main forum for debate on public health reform in Tasmania.

Key Words: epidemic diseases, sanitary science, statistics, public health, doctors, The Royal Society of Tasmania

INTRODUCTION

One of the most striking developments in England and Wales between 1700 and 1911–15 was the decline in the crude death rate from 27.9 deaths per 1000 living, to 14.3 deaths and the increase in average life expectancy at birth from 37.1 years in 1701 to 53.5 in 1910–12 (Harris 2004). In the last two decades of the nineteenth century, "the rate of overall mortality decline noticeably accelerated, and the early decades of the twentieth century witnessed a precipitous reduction in mortality" (Bell & Millward 1998, p. 223). Around 1840 infectious diseases were responsible for about 40% of all urban deaths, but by 1900 this had dropped to less than 20% (Szreter & Hardy 2000). Historians have offered various explanations for the conquest of disease and the decline in mortality, especially in the nineteenth century. These included the development of "new scientific medical procedures and discoveries", changes in the virulence of diseases, improved medical attendance and education, improved nutrition and public health reform (Berridge 1990, p. 195). While it remains true that it will "never be possible to apportion credit with total accuracy to the many preventative measures that contributed to the decline in urban mortality", historians have tried hard to win converts to their preferred explanation and contributed to a lively debate (Kunitz 1993 p. 291). Medical historian Milton Lewis has surveyed a similar debate in Australia and concludes that by 1900 disease was prevented "through environmental sanitary regulation—reinforced by publicly run reticulated water and underground sewerage systems, at least in the larger colonial cities—and controls over infectious diseases through the practice of notification, inspection, disinfection and isolation" (Lewis 2003, p. 72).

The debate amongst historians on the causes of disease, the methods to stop their spread and the reasons for mortality decline also occurred in nineteenth century Britain. The forums for such debates included august scientific bodies like the Royal Society in London (Hall 1984, Batty Shaw 1968) and in Edinburgh (Campbell & Smellie) as well as the Royal Medical and Chirurgical Society (from 1907 the Royal Society of Medicine) (Davidson 1955, Hunting 2002). But debates were also carried on in a number of other, more specialised bodies such as statistical societies (Cullen 1975), epidemiological societies (Lilienfeld 1978) and the Social Science Association (Huch 1985, Goldman 2002). Debate was stimulated not only by meetings of these societies, but also in their respective publications and in more general magazines, quarterlies and reviews (generally see Daunton 2005).

The aim of this paper is to examine the role played by The Royal Society of Tasmania, Tasmania's pre-eminent scientific and cultural institution, in acting as a forum for the discussion of public health reform and medical issues in the nineteenth and early twentieth centuries. Doctors and sanitary reformers used meetings of the Royal Society to argue the case for sanitary reform, but their views did not always go uncontested and some opposition to reliance on expensive public health measures did surface at meetings. Papers presented at Royal Society meetings often referred to British developments and varied from statistical analyses describing the state of health, propositions on the causes of infectious diseases, especially typhoid, and methods to combat disease and improve public health, in particular by improving water supply and building an underground sewerage scheme for Hobart.

Established in 1843, The Royal Society of Tasmania is Australia's oldest scientific society. It was formed "to develop the physical character of the Island and illustrate its natural history and productions" (Pearson 1943, pp. 224–26, Somerville 1943). Its aim was broadened in 1907 to include "the prosecution of the study of science in its various branches" and in 1914 the aim was enlarged to become "the advancement of knowledge" for the benefit of Tasmania. Various sections were formed on different subjects. These sections included Botany, Zoology, Geology, Palaeontology, Anthropology and History and Geography (Petrow 2003). Two sections are of direct relevance to this article and reflected the sizable number of medical doctors who had always been associated with The Royal Society of Tasmania (Hoare 1969, Paull 2011). One was the Physical, Mathematical and Mechanical Section, which entailed an interest in health and lasted only briefly in the 1860s

(Winter 1972). The other section was the Medical Section, which existed from 1896 to 1911 (Somerville 1943). In 1907 a reorganisation of the Royal Society resulted in the formation of Section B on Medical Science, but official publications still referred to the medical section (PPRST 1907). The Launceston district of the Victorian branch of the British Medical Association was formed in 1897 (*Launceston Examiner* 1897), but it made no effort to affiliate with the Royal Society and periodically held its own lectures on technical subjects (*Launceston Examiner* 1898).

The most significant contribution to public health reform was the number of articles on health matters published in the *Papers and Proceedings of the Royal Society of Tasmania.* The articles were usually published in local newspapers and generated debate inside and outside the society. Royal societies in other colonies held lectures and published articles on health as an important "public" issue (Inkster & Todd 1988), but it does not appear that medical sections were formed in Queensland (Marks 1959), South Australia (Rogers 1922) or Western Australia (Jenkins 1965), while in Victoria the medical section, like other sections, functioned "either not at all or, at the best, only spasmodically" after 1858 (Pescott 1961, pp. 13, 23). In New South Wales a Medical Science section was formed in 1876 and was one of the "most active" until separate societies and a medical school at the University of Sydney were established (Elkin 1968, p. 22).

Many of the articles published by The Royal Society of Tasmania before 1880 were not "theoretical and speculative" or even of particular "scientific" interest (Winter 1972, pp. 35, 54, 71). Instead, the articles were "practical, useful contributions, which would assist settlers in a new land". Lectures also dealt with "matters of public interest" and helped stimulate public debate (Somerville 1943, p. 207). As Pearson (1943, p. 226) put it, Society Fellows courageously promoted "new ideas and ideals, a process which is generally anathema in an isolated, self-contained community". The articles on health and medical issues reflect that assessment and were intended to alert the Tasmanian community to the latest developments in sanitary science that could help reduce the incidence of infectious and other diseases. We can analyse the kind of articles published in two phases. The first phase, between 1853 and 1896, dealt predominantly with sanitary reforms of interest to the Tasmanian community and in the second phase, between 1896 and 1911, doctors showed more interest in technical medical matters and were more inward-looking, but some papers on sanitary reform were discussed.

PHASE 1: 1853–1896

Public health attracted most interest amongst Fellows of The Royal Society of Tasmania after epidemics of infectious diseases occurred. In November 1853 a paper by the President, Lieutenant-Governor William Denison, drew a direct connection between the recent outbreak of scarlet fever and the "the present imperfectly drained state of Launceston and Hobart Town" (*Courier* 1853 p. 2). Denison had been a member of the Health of Towns Commission in 1844, which enquired into the condition of large towns in England and Wales, and he quoted from the Commission's reports to highlight the importance of drainage and sewerage to "the physical and moral well-being of the community" (Denison 1854, p. 371). The meeting resolved to draw the attention of the municipal councils of Hobart and Launceston to Denison's paper, which was published in 1854 (Denison 1854). The Launceston municipal council took Denison's admonition to heart and in March 1857 aldermen asked him to choose the best scheme for sewering the town (Petrow 2003b). He chose one called "Sub Spe" by W.C. Bennett, Assistant Engineer in charge of Sewerage, Sydney and W.R. Wade, Assistant Engineer of the Sydney Water Works. The Launceston Council began work on "Sub Spe" in August 1860.

Another contributor on health matters was one of Hobart's leading doctors, Dr E.S.P. Bedford, who attributed the scarlatina outbreaks of 1852–3 to the disease's "peculiar germ, or poison", but its "spread and its severity [was] influenced by all those circumstances which impair general health" (Bedford 1854, p. 460). Bedford also contributed one of the few technical papers, on the origins of nervous shock (Bedford 1863).

The most prolific contributor on public health matters before 1896 was Dr Edward Swarbreck Hall. For being the first doctor "to preach the gospel of public health with an inspired intelligence and courageously to fight for health reforms in the face of great obstruction", Howard Cumpston (*The Mercury* 1923), the first Director-General of the Commonwealth Department of Health, anointed Hall as "The First Australian Sanitarian". Born in 1804, Hall studied medicine at Liverpool, England and completed further studies at the School of the Royal College of Surgeons in Dublin and at St Bartholomew's Hospital Medical College in London (Haynes 1978).

He practised medicine in Liverpool but, after his wife's health declined, decided to move to the healthier climes of Van Diemen's Land, arriving in 1833. His various appointments in different parts of the penal colony helped broaden his medical experience, in particular in dealing with epidemics of infectious diseases. Such diseases devastated local communities and Hall developed an interest in how to prevent their recurrence. Hall resigned from government service in 1855 and resumed private practice at Hobart, thus freeing him "from the many restrictions, both political and social, which Government service imposed" (Haynes 1978, p. 138). Soon Hall was transformed from "the conscientious Government servant who was anxious to abide by the regulations to the outspoken medical and social reformer".

In his new role as sanitary conscience, Hall had ample scope for improving the situation in Hobart. The city was unsewered, the water supply was inadequate, public and private buildings lacked ventilation and overcrowding was common (Petrow 1995). The municipal council and most citizens were apathetic and did nothing to remove the rubbish that littered streets and backyards, all exposing residents to infectious disease. In his battle against apathy, conservatism and vested interests, Hall found allies in the local press, first in the *Tasmanian Daily News* and later *The Mercury* (Haynes 1978). They published his speeches and papers to The Royal Society of Tasmania and his letters and statistical studies, as well as reporting on developments in public health in Britain and America. The press also fully exposed the impact that epidemic disease had on urban residents.

While Hall was a passionate critic, he did not let emotion outweigh reason. He based his arguments on first-hand, detailed, empirical research, in the tradition of the great English sanitary reformer Edwin Chadwick (Finer 1952). As Hall noted, "the master minds of the profession are now

assuming the first duty of medical skill to be to prevent disease" and that the collection of facts and figures were "the great levers which enabled sanitary reformers to effect their brave and bloodless victories" in saving human lives (Hall 1862, p. 42). Hall relied on vital statistics to demonstrate the impact of epidemics. In the mid-1850s he spent endless hours in the Registrar-General's office investigating returns and compiling tables of statistics and he later became a member of the Statistical Society of London (Haynes 1978).

In his papers to the Royal Society, Hall (1863a, b) was a strong advocate of sewering Hobart. He marvelled at how "the application of the science of Hydraulics" had "largely" resulted in "the great triumphs of improved health, increased comfort and prolonged life" in the cities and towns of Great Britain (Hall 1863a, p. 5). More significant was Hall's fruitful collaboration with another Royal Society of Tasmania Fellow, the Registrar-General Francis Abbott, in investigating the connection between the occurrence of disease and the weather (Haynes 1978). They attempted to prove that it was upon the hourly and daily changes of atmospheric phenomena that the healthiness or otherwise of any climate depended. They postulated that the amount of ozone in the atmosphere might account for the lower mortality rate in country districts than in Hobart and that generally Tasmania's large amount of ozone helped mitigate the effect of some epidemic diseases, such as influenza. Hall was "not aware that I have been anticipated in ... attempting to minutely apply the treasures of vital statistics, of daily meteorological observation, of accumulated medical experience, to elaborate laws of health, and produce a harmonious union of our respective labours" (Curson 1985, p. 109).

Hall published "very numerous and instructive" papers on climate and health between 1856 and 1872 in the *Papers and Proceedings of the Royal Society of Tasmania* (Morton 1900–1901, p. 124). Hall's reports on the health of Hobart compared the number of deaths in the month with that of the previous month, and then with the same month in the preceding six years (Haynes 1978). He divided deaths into age groupings and into fifteen different classes or causes of death, ranging from zymotic diseases to old age. The meteorological information included readings of the barometer, thermometer, and the wet bulb thermometer, records of solar intensity, elastic force of vapour, rain, wind force, and amount of ozone. Hall ended by summarising the positive or negative impact of the weather, and providing advice on future action.

Hall's statistical analyses showed that Hobart experienced a very high degree of infant mortality and that the meteorological phenomena were characterised by large fluctuations in barometric pressure and temperature (Haynes 1978). Hall linked the two factors and added a third, the carelessness of man. He found that a rising barometer with a falling thermometer was invariably followed by an increase in deaths both of adults and children. Croup, convulsions, diarrhoea and dysentery were the main causes of infant mortality. Hall became especially agitated by the high mortality rate at the Queen's Orphan School and made enemies of influential senior members of the medical profession by bringing this fact to public notice at the September 1857 meeting of the Royal Society. Dr E.S.P. Bedford, the Orphan School's Medical Officer, described Hall's statistics as "erroneous and unjust" and "founded upon insufficient data" (*Courier* 1857a, p. 2). Bedford claimed that Hall had selected two or three years when deaths were very high as his mean "instead of an average being deduced from a series of a dozen years or more". Bedford attempted to divert attention from himself by questioning Hall's assertion that Tasmanian wheat was deficient in gluten, a subject on which experts differed (*Hobart Town Daily Mercury* 1858a, b, c). Hall had suggested that lack of nutrition contributed to the death rate and therefore that children in the Orphan School should receive a larger ration of animal meat to ensure that they consumed an adequate amount of nutritious food. Fellows were concerned that, if Hall's paper was published, the reputation of the wheat industry would be damaged and this would be detrimental to Tasmania's economy. After a lengthy debate, they overwhelmingly decided not to publish Hall's paper because it was based on questionable evidence (*Courier* 1857b, c). Hall was not deflated by this decision and dismissed Bedford's "old-fashioned and unscientific approach to medicine" (Rimmer 1981, p. 81). Whether due to Hall's agitation or not, during the first half of the 1860s deaths at the Orphan School declined in line with the general death rate (Hall 1865).

In 1860 Hall's contribution to the study of disease was recognised when he became a corresponding member of the Epidemiological Society of London, which was becoming an influential medical and scientific body (Haynes 1978). He was also made an Honorary Member of the Medical Society of Victoria, which proclaimed him to be "the ablest authority on Medico-Vital Statistics in the Southern Hemisphere" (Haynes 1978, p. 280). By the 1860s Hall had established a world-wide reputation as a medical statistician and a sanitarian. He was supremely confident of the correctness of his mission, was convinced that the evils of Hobart were due to local and remedial causes and was heartened by the improvements that were slowly gaining ground. He continued to criticise the status quo and to suggest practical reforms based on his wide reading in medical journals and his correspondence with sanitarians around the world.

In the 1860s Hall had been, in effect, the unofficial Health Officer for Hobart. In his articles in the *Papers and Proceedings of the Royal Society of Tasmania* and in small articles on particular subjects for the press, his work as a sanitarian was limited to pointing out abuses. In a long paper read to the Royal Society in March 1872 entitled "Climate and Statistics in Tasmania" based on the statistical tables he had compiled between 1857 and 1871 (PPRST 1872, pp. 3–4) and later published separately, Hall conceded that statistically deaths in Tasmania had undergone "a great reduction of late years", but he lambasted the Hobart municipal council for its neglect of sanitary matters. He warned that "man's care has so far done little to obviate those hygienic drawbacks which the concentration of a city population will produce whatever may be the climatic and local advantages, unless special care be taken" (Hall 1872, p. 21). The President of the Epidemiological Society, Inspector-General Robert Lawson, described Hall's study as "a model for any work of this kind" (*The Mercury* 1873, supplement, p. 2).

The 1875 epidemics of measles and typhoid shook aldermen out of their complacency and with press and government encouragement they appointed Hall as Health Officer in November 1875 (Petrow 1995). Throughout his period as Health Officer, Hall received little support from aldermen and lacked legal power to carry out effective sanitary reform without that support. To be sure, some

successes were achieved. In 1880, for example, the council was empowered to borrow money to improve the water supply and to clean up and permanently improve the Hobart Rivulet, which Hall had advocated. But generally Hall's message that expenditure on preventive measures, such as an underground sewerage scheme, would save money in the long term was not easily grasped by cheese-paring aldermen before his death in July 1881.

Between 1875 and 1896 the *Papers and Proceedings* contained a number of papers that highlighted sanitary problems in Tasmania. In 1875 Government Statistician E.C. Nowell, noting Tasmania's economic disadvantages, suggested that her great advantage was her "superior" climate, which was especially beneficial for the health of children and tourists (Nowell 1875). Tourists were attracted by cool temperatures, beautiful scenery and "a reputation for salubrity", but they would be deterred from visiting the island, Nowell warned, unless Tasmania adopted "efficient means of removing all those causes of disease which are under our control" (Nowell 1875, p. 115). The Bishop of Tasmania, Charles Henry Bromby, a member of the Statistical Society of London and a former secretary to the statistical section of the British Association for the Advancement of Science, thought Nowell's paper was of "importance to the community at large" (*The Mercury* 1875, p. 3). He suggested that Hobart's chance of becoming "the naval station of the colonies" depended upon "the proofs we can give as to the salubrity of our climate".

Bromby presented his own thoughts on the relationship between water and disease in 1878. He blamed outbreaks of typhoid, scarlet fever and diphtheria on drinking from "stagnant wells, befouled by vegetable decomposition, animal refuse, and disgusting drains and miasmatic cesspools" (Bromby 1878, p. 56). He subscribed to the germ theory of disease causation and urged "the Sanitary Reformer" to prevent germs from growing and multiplying by protecting Tasmania's "noble water-fields" from contamination. Bromby quoted Swarbreck Hall, who thought Bromby's address would have "a beneficial effect" because when "respected and intelligent gentlemen took up sanitary subjects, it would have more weight with Government and local authorities than anonymous letters to newspapers" (*The Mercury* 1878a). Bromby's paper was reprinted in *The Mercury* (1878b).

Bromby thought expense might be one obstacle to reform, but another was differences over disease causation. The Secretary and Royal Society stalwart Dr James Agnew, observed that, although the germ theory was "a good working theory, it was well to recollect its correctness had never yet been actually proved" (*The Mercury* 1878a, p. 3). He believed that infectious diseases occurred '"*de novo*—that is without the action of any pre-existing germ". He cited the anti-germ theory research of Dr Benjamin Ward Richardson, F.R.S. (1877) (Worboys 2000). Richardson, a pioneer of the British sanitary movement, suggested, claimed Agnew, that infectious diseases were caused by "a poison secreted by the individual", which was "conveyed from one individual to another by the air, by various fluids, or by personal contact" and produced "certain (catalytic) changes in the secretion of the part to which it was applied". In some cases poisonous secretions resulted from "certain nervous influences inducing diseased local secretions" and thus infectious diseases might begin "*de novo*".

Another skeptic of the germ theory was Nowell's successor, Government Statistician Robert Mackenzie Johnston, who was a "prolific contributor of papers", mainly on geological and statistical topics (Winter 1972, p. 74). Johnston was influenced by a paper published in the *Journal of the Statistical Society of London* by B.G. Jenkins (1879), who posited "a probable connection between the yearly death-rate of England and the planet Jupiter in his orbit" (Johnston 1884a, p. 236). In 1884 Johnston, after completing his own analyses, suggested that fluctuations in death rates in the Australian colonies were due to "some super-terrestrial influence of a variable character, which has the effect of intensifying or modifying the death-rate to such an extent that the local causes appear as mere ripples on the swell of a great wave in conjunction with it" (Johnston 1884a, pp. 237–38). In particular he identified the rise and fall in death rates as linked to Jupiter's movement between "aphelion" and "perihelion". In Australasia the death-rate was low "during years of sun-spot maxima" and high "during years of sun-spot minima". Australia's mean death rate over the twenty years to 1884 was lower than Europe's because it was "comparatively unaffected by those artificial evils attended upon crowded centres of population" and had a "fortunate immunity from the pestilence of war". Freedom from "artificial disturbances" made Australasia "a more sensitive index of complex super-terrestrial influences". But Johnston concluded that "the death-rate coincidences are not sufficiently broad and regular to justify prediction" and the phenomena were "more suggestive than conclusive".

Based on his reading of an abstract of Johnston's paper in *The Mercury*, distinguished local astronomer Alfred Biggs (1884, p 277) took issue with Johnston over whether death-rate fluctuations "might correspond with and be dependent upon *either* the sun-spot periodicity *or* the position of Jupiter in his orbit". Biggs argued against coupling "the two phenomena of Jupiter and sun-spots, inasmuch as the periods, although very nearly equal, are not quite so". As Jupiter's mass was "less than one-thousandth part of that of the sun and his mean distance 480 millions of miles", Biggs thought it "difficult to conceive of any particular influence that he could exert upon the sun under any circumstances". Biggs (1884, pp. 278–9) did, however, countenance the possibility that "physical changes in the sun, such as variation in spottedness", could affect "our mortality curve", but ultimately concluded that "solar observations and vital statistics have not run together long enough to establish the fact of any connection between them". He observed that the rise in death-rates in the last two years correlated with "a period of abnormal telluric disturbance" and with "abnormal atmospheric conditions, as shown by our recent *sunset glows*". If there was a connection, Biggs (1884, p. 280) rightly pointed out that, "unlike sanitary arrangements which are supposed to engage the attention of our municipal authorities", the extra-terrestrial phenomena were "absolutely beyond our control". Johnston (1884b, pp. 280–81) welcomed Biggs' interest in the subject, but regretted that he read an abstract and not the full paper. This led him to assume "erroneously" that "the relations commented upon are *simple* instead of *complex*" and to assign "*mutual inter-dependence*" between phenomena where Johnston only "observed *coincidence*". Johnston acknowledged "many unexplained anomalies due to unknown and complex relations" and said that more proof was needed.

Esoteric debates like the one between Johnston and Biggs were uncommon. Tasmanians became increasingly preoccupied with tackling more fundamental, practical

problems such as the pollution of water, which was the subject of a paper by the Government Analyst and chemist W.F. Ward (*The Mercury* 1931). In 1885 the Sanitary Officer of the Launceston municipal council J.G. Bushman sent Ward his analysis of water samples from different locations, which showed "painful neglect of the simplest necessary health precautions" (Ward 1885, p. 116). Ward (1885, p. 123) subscribed to the view that typhoid was "spread by the contamination of water or air by a specific poison derived from the discharges of infected persons" and that this poison consisted of "living germs, although they have not yet been absolutely identified". Ward (1885, p. 124) thought it of "the highest importance" that the water supply of towns "should be preserved from the risk of contamination by the prohibition as far as possible of all settlement on gathering grounds". Ward's paper was well received by Johnston, Drs A.B. Crowther and H.A. Perkins, and Richard Bastow, who had worked for the Health Department of the Manchester City Council (Petrow 1995). There seemed to be general agreement that germs contributed to the spread of disease and that sanitary reforms, including ensuring the purity of water, were needed to protect Tasmanians from further epidemics, but some issues remained unsolved (Ward 1885, pp. 125–30) Perkins asked: "Were the germs brought to the colonies by passengers in ships, or had they been present in the world from the beginning of all creation, ranking with the first origin of all things? Was it that the germs were not noxious—things to be hated—and not merely things for the transmission of disease to man, but having their own rank in the scale of creation? Was the fact of the transmission of disease by them a mere accident, or the result of man's own fault?" (Ward 1885, p. 128).

Perkins was disappointed that the Public Health Bill 1885 about to be presented to Parliament, left power to keep water supplies pure in "local hands, which, in his opinion, would not tend to work satisfactorily" (*The Mercury* 1885, p. 4). Although municipal councils were notoriously lax in keeping water supplies free from contamination, they won the battle to retain that responsibility.

More positively, the enactment of the Public Health Bill created a Central Board of Health , which appointed Alfred Mault as its Engineering Inspector. Mault succeeded Hall as Tasmania's pre-eminent sanitarian. In a complementary paper to Ward's, Mault spoke on drainage and sewerage of Hobart to the meeting of The Royal Society of Tasmania in August 1886. The talk was an abridged version of his 1886 report on the sanitary condition of Hobart and was designed to stimulate debate on the relative merits of surface drainage and underground drainage (Mault 1886). Mault estimated that it would cost £20,000 to complete the system of surface drainage and that the annual cost of keeping it in working order, including £9,000 for emptying pails of nightsoil and paying interest on the £20,000, would be £16,300. Mault preferred an underground sewerage system, which would use water closets and carry sewage into the estuary's tideway. This system would cost £60,000 to build, with an annual cost of £7,000 including interest. This system entailed provision for "mechanical or chemical … purification" of the sewage before reaching the outlets (Mault 1886, pp. 30–31). Hobart was especially suited to such a system because fifteen million tons of water flowed down the River Derwent each day and this large body of flowing water would easily accommodate 1⅔ tons of "solid faecal matter", but Mault was concerned about discharging "liquid excreta and house slops" (*The Mercury* 1886a, p. 3).

Mault's paper received a lukewarm response. Draughtsman and drawing teacher W.H. Charpentier noted how refuse, and even excreta from ships in the harbour and the Hobart Rivulet ended up on the nearby beach and he doubted that the sewage would be carried far enough away from Hobart (*The Mercury* 1886a). He preferred the dry earth system because it could produce "marketable manure" and typhoid was "always found wherever the water closet system was adopted". Others also supported the dry earth system and thought that Mault had underestimated the cost of an underground system. Dr Perkins supported Mault's proposal, but also wanted the outlets taken further out to sea. At a subsequent meeting, when Bastow read a paper questioning Mault's views, most Fellows tended to oppose Mault's scheme largely due to doubts about his estimated cost, concerns about the safety of water closets (sewer gas being a particular danger) and opposition to the pollution of rivers (*The Mercury* 1886b). Although Perkins and Mault effectively answered the critics, the opposition of the Royal Society Fellows largely reflected concerns of ratepayers, who would bear the heavy cost of underground drainage (Petrow 1995).

Johnston proceeded to investigate further the causes of death in Tasmania and presented his findings to the Royal Society in 1887. He argued that the total death-rate as "a test of comparative health and sanitary condition" was "misleading" and cited Hobart as an example (Johnston 1887, pp. 22–23). When compared with Sydney, Brisbane, London and Adelaide, Hobart had the highest death-rate of 24.70 per 1000 in 1885. But Hobart also had by far the highest number of deaths in people aged over 60 at 43.46 per cent of all deaths, the next closest being Adelaide at 18.80 per cent. The mean age of death in Hobart was also the highest at 74.30, with London next at 73.37, and Johnston argued that longevity was an important indication of the health of Hobart. When only deaths under 60 were considered, Hobart's death rate was the lowest at 13.97 per 1000, with Adelaide next at 15.42. Johnston also took into account other factors such as migration, the birth-rate, the influence of climate and the season, the density of population and hygiene. Inevitably, Johnston remained partial to "cosmical or obscure causes", but he admitted that in England during the previous 20 years sanitation and improved medical treatment had done much to lower the death-rate of "younger lives" and believed that "human effort" could do much "to mitigate the intensities of attacks on disease, from whatever source they come, even if it cannot wholly subdue them" (Johnston 1887, p. 30).

Johnston's analysis was not without critics. Dr C.J. Parkinson questioned Johnston's age limits, especially fixing the upper limit at 60 instead of 65 or 68 (*The Mercury* 1887, supplement). More pertinently, Parkinson doubted that Johnston had made a case for the superior "health and sanitary condition" of Hobart and suggested comparing Hobart with "health resorts" with similar populations, such as Cheltenham, Hastings and Eastbourne rather than a large metropolis like London. It also made more sense to compare Hobart with colonial towns with similar climates like Christchurch and Dunedin, rather than with colonial capitals like Brisbane and Sydney. Parkinson thought it unnecessary to invoke "a hidden cosmical influence" as the cause of typhoid when local hygiene and seasonal influences more than adequately explained "this fearful epidemic of a filth disease amongst us". Mault feared that Johnston's paper would retard rather than aid sanitary work. Mault

asserted that "sanitary science and the inculcation of the duty of cleanliness can override such cosmical influences as were at work". He thought that they should look at death from preventible disease as "a homicide chargeable to something or somebody".

Although by 1887 very few people doubted the efficacy of sanitary reform when it involved cleaning up the environment, Mault still found it hard going convincing Hobartians to accept the discharge of sewage into the River Derwent, but received encouraging support from the Royal Society when he delivered a paper on the topic in 1893 (Mault 1893). Support for sanitary reform was most certainly due to a series of typhoid epidemics that affected Hobart in 1887, 1888, 1889 and 1891 when the death of people in "the prime of life, especially males between the ages of 20 and 35 years, was unusually large" (Johnston 1896, p. 1). This resulted in the formation of pressure groups such as the Sanitary and General Improvement Association and the Women's Sanitary Association to push for sanitary reform (Petrow 1995). But Johnston told the Royal Society in 1896 of a noticeable drop in deaths from preventable diseases like typhoid in 1894 and 1895. Johnston (1896, p. 13) asserted that this drop had little to do with "local, artificial, or sanitary provisions" and its low death-rate made Hobart "pre-eminently one of the most healthy cities in the world". Johnston criticised sanitary "enthusiasts" for being "alarmists" who were "ever prone to exaggeration" and condemning the sanitation and health of Hobart as being "unexceptionally bad", which scared away tourists and their much needed money.

Statistics indicating "the comparative superiority" of Hobart did not go uncontested. Discussion after Johnston's paper produced different statistics and interpretations to show Hobart's high death rate from preventable diseases. Mault admitted that Johnston's statistics on general death rates proved Hobart to be "one of the healthiest cities in the world", but he was astonished by Johnston's implication that "better sanitary administration" had not reduced deaths in other Australian cities (Johnston 1896, pp. 16–18). Mault's statistics showed that typhoid was one disease that sanitary work could reduce and even eliminate and that Hobart, "though a very healthy place, may be made yet more healthy by the prevention of typhoid". Johnston remained adamant that sanitary changes alone could not explain the drop in deaths from typhoid and suggested that the role of "the increased knowledge of medical men in the treatment of such diseases, and the improved habits of the people" needed more acknowledgement. But he hoped his paper would not distract attention from "the importance of sanitation" (Johnston 1896, p. 21).

While typhoid absorbed most discussion at Royal Society meetings, it was not the only disease to cause concern. In 1896 Dr Gregory Sprott, newly-appointed Health Officer to the Hobart municipal council and fresh from an Intercolonial Medical Congress in Dunedin, spoke to Fellows about tuberculosis, "one of the most widespread diseases we have to deal with", which caused "more suffering to humanity than any other known disease at the present time" (Sprott 1896, p. 45, Roe 1999). Tuberculosis was another disease to cut off young men and women in their "prime" and those who did not die often became "chronic invalids, incapacitated for work". Although German doctor Robert Koch had identified "the bacillus tuberculosis", Tasmania had done very little to stop its deadly spread by for example minimising spitting by consumptives. The work of doctors would be bolstered if people were educated as to "the cause and nature of this disease and the measures which will prevent it" (Sprott 1896, p. 60). Meat and milk supplies needed to be tightly regulated and inspected and housing needed better ventilation.

PHASE 2: 1896–1911

In the late nineteenth century the colonies experienced an influx of doctors from Britain and, as many had been members of the British Medical Association (B.M.A.), they naturally sought to form colonial branches (Johnson & Caygill). It appears that a Tasmanian branch of the B.M.A. was formed in 1889, but it had dissolved by 1892 (Johnson & Caygill). Moreover, in the absence of a Medical School (one was mooted in 1896) at the newly-formed University of Tasmania, doctors clearly felt a need to discuss aspects of their professional practice and new developments in medicine (Davis 1990). An obvious solution was to establish a more formal relationship with the pre-eminent scientific body, The Royal Society of Tasmania. In November 1896 a medical section of the Royal Society was formed with seventeen members, including six doctors who joined on 16 November (*The Mercury* 1896). The Royal Society generously granted the section £12 a year towards the cost of medical books, provided the section had not less than twelve members (Somerville 1943 RSA/A/5). Dr R.S. Bright was the first President. Trained in London, Bright began practising in Hobart in 1859 and became one of the leading doctors (*The Mercury* 1901).

At the annual general meeting of the Royal Society in 1897 Bright announced that nearly all the doctors in Hobart had "expressed their willingness to join" and preferred "to affiliate themselves as a branch of the Royal Society than to form an independent Medical Society of their own" (*The Mercury* 1897a, p. 3). At its first annual dinner in October 1898 Dr Butler thought the section had done "a large amount of good work" (*The Mercury* 1898c, p. 2). It gave doctors a chance to meet together and exchange ideas on "all matters relating to their professional work". It promoted "those kindly feelings which ought to exist amongst members of the profession". Section meetings were held in committee and were not reported in the press as were the monthly meetings of the Royal Society (*The Mercury* 1905a)

At meetings of the section members delivered papers on a range of "highly technical" medical topics (Somerville 1943, p. 209). For example, of the seven papers given in 1897 Dr S.C. Jamieson spoke about a "New Method of Treating Empyema" (*The Mercury* 1898a, p. 3) and of the eight papers given in 1898, Dr Wolfhagen related "Some Unusual Complications after Laparotomy" (*The Mercury* 1899, p. 4). Members exhibited specimens of various kinds such as in its first year a "large calculus", Tasmanian skulls and a horseshoe kidney (*The Mercury* 1898a, p. 3). The nature of the papers given at section meetings were not always specified after 1898, but sometimes members read papers at the monthly meeting. In August 1898 Dr A.H. Clarke spoke about his "Notes on a Surgeon of the Tudor Period and his work" (*The Mercury* 1898b, p. 4). Clarke highlighted how "improvements in surgery since anaesthetics have combined to make operations so much easier and safer" (*Examiner* 1900a, p. 7). Some papers read at monthly meetings were also technical in nature. For example Dr Gerard Smith expounded on "The Biological

Ancestry of Some Human Diseases" (*The Mercury* 1906a), Dr E.J. Roberts (1906–7) discussed anti-toxins in his "The Germ as a Friend in Therapuetics: Notes on the Opsonic Index" and Dr E.J.W. Ireland (1910) considered "Skin Diseases Treated by Blood Vaccine".

Public health remained a popular topic and Sprott gave two papers to monthly meetings. In July 1897 he trumpeted the virtues of cremation. Sprott argued that "as we become better acquainted with the life history of disease germs, and the part they play in the causation of infectious diseases, we will be forced, whether we like it or not, to find a more sanitary way of disposing of our dead than by our present mode of burial" (Sprott 1897, p. 13). Sprott thought that the religious and sentimental objections to cremation would be overcome in time by an educational campaign on its advantages (*The Mercury* 1897b). In 1898 he was even more impassioned in favour of an underground drainage system for Hobart and his paper, which was not published in full in the *Papers and Proceedings*, showed how an underground drainage scheme had reduced the death-rate from typhoid in "numerous cities and towns" (*The Mercury* 1898b, p. 4). He hoped that "no private or selfish interests" would stop a reform that would "improve the health of the people". Those present overwhelmingly supported underground drainage. Further papers by mainland sanitary experts, Jamieson (1902) and Wilkinson (1902), merely confirmed the effectiveness of a properly constructed underground drainage scheme and accompanying purification process. In 1903 an overwhelming number of ratepayers voted for such a scheme (Petrow 1995).

Another distinguished contributor on health matters was Dr J.S.C. Elkington, who served as Tasmania's Chief Health Officer from 1903 to 1909. Elkington introduced two new subjects. In 1904 he analysed the link between insects and disease, noting the role of mosquitos in spreading malaria and fleas in spreading the plague. More pertinent to Tasmanians was the "ubiquitous" house fly, which conveyed on its feet and body "the germs of disease" (Elkington 1904, p. 11). Elkington thought that flies were responsible for "a fair proportion of cases of communicable disease", especially typhoid and even perhaps smallpox and urged housewives to eradicate them. Elkington was a pioneer in school hygiene (Roe 1984) and stressed the importance of that subject in a paper delivered to a receptive meeting in 1906. They could stop children "spoiling their eyesight, curving their spines, and doing themselves all sorts of injuries" if schools were "properly built and modern appliances [were] used" (*The Mercury* 1906b, p. 6). Elkington also believed in greater physical activity for school children and medical inspection of schools.

Elkington's most controversial paper was given in 1905 when he exhaustively discussed "Some Social and Economic Aspects of Health Work". Elkington asserted that the "standard of a community's progress" could be measured by "its sanitary administration and by the proportional fund allotted for the purpose" and said that how much was allocated by the State depended upon the level of public support (*The Mercury* 1905b p. 7). He estimated that Tasmania spent 2.16 pence per head of population on sanitary administration, but if six pence was spent they could achieve "real efficiency" and nine pence would be "absolute luxury", preventing outbreaks like Launceston's smallpox epidemic in 1903. Elkington pointed out that Tasmania was behind Victoria at 4.2 pence per head per year, New South Wales at 5.8 pence and New Zealand at 9.6 pence. While the major cities now recognised "the benefits of applied sanitation", most of Tasmania was "barbaric in its primeval insanitation". Elkington saw the solution in greater centralisation of sanitary administration as was the case in New Zealand (*The Mercury* 1905c, p. 7).

Giving papers was a normal part of Royal Society activities, but the medical section went further and acted as a lobby for doctors and health reform (*The Mercury* 1908a), often joining forces with the Launceston district of the Victorian branch of the B.M.A. in "matters of mutual interest" (*The Mercury* 1899, p. 4). Tasmanian doctors were far more organised before a Tasmanian branch of the B.M.A. was formed than McWhirter (2003) implies. In 1900 the medical section supported giving Launceston doctors more involvement in the running of the Launceston General Hospital (*Examiner* 1900b, Craig 1963). Both medical bodies combined to hold the Australasian Medical Congress in 1902 (*The Mercury* 1902a). In Hobart the medical section supported the establishment of a Maternity Hospital as long as patients could engage their own doctors (*The Mercury* 1902b), but opposed making tuberculosis a notifiable disease "without effective follow-up" (Roe 1999, p. 40). Following the smallpox outbreak in Launceston in 1903, the medical section advocated "a more thorough system of vaccination" and giving power to the Central Board of Health to vaccinate compulsorily anyone who came into contact with a smallpox case. The section also supported building an infectious diseases hospital in Hobart and smaller hospitals in country areas (*The Mercury* 1908a) and establishing "a depot for the supply of humanised and pure milk" as "necessary for the conservation of infant life" (*The Mercury* 1909, p. 2).

None of these interventions seems to have been questioned, but in 1903, when the medical section opposed the confirmation of Dr Gerard Smith as Health Officer for Hobart because "such an important position" should not be held by "a homeopathic practitioner", the section did incur criticism (*The Mercury* 1903, p. 6). Writing to *The Mercury*, "No Close Borough" pointed out that the Royal Society had been formed to advance science and the study of natural history, but the medical section was travelling "a long way outside those functions" in attacking their "legally-qualified brother medical practitioner" (*The Mercury* 1903, p. 6). If the doctors formed their own independent society, then they could black-ball anyone they wished, but they should not do so under the imprimatur of the Royal Society.

It appears that Hobart doctors were intent on defending their professional position and formed a Tasmanian branch of the B.M.A. in July 1911 when Sprott was elected its first Chairman (NS168/1/1, Rimmer 1981). Even then, the eighteen members of the section requested that the branch be allowed to affiliate with the Royal Society, which was agreed to "subject to certain conditions" (PPRST 1911, p. 401). But soon the affiliation lapsed and the B.M.A. merely paid an annual subscription for the use of the Society's room and the medical books (Somerville 1943). By 1914 two-thirds of doctors in Tasmania had joined the B.M.A., which became a powerful interest group (Rimmer 1981). Until 1916 the B.M.A furthered its aim to "promote the advancement of medical science" by encouraging members to give lectures on medical topics, but "clinical meetings had ceased entirely by late 1916" and the protection of professional interests dominated (NS 168/1/1, McWhirter 2003, pp. 21–2, 79). After the departure of the medical

doctors, papers on medical topics were rarely published in the *Papers and Proceedings*, which were dominated by papers on botany, zoology and geology.

CONCLUSION

In the nineteenth century infectious diseases proved to be deadly killers around the world and doctors and sanitarians spent much time debating the best methods to stop the spread of diseases like typhoid and tuberculosis. In Tasmania these issues were discussed in the newspapers whenever epidemics broke out, but The Royal Society of Tasmania, as the most highly respected scientific body, was a valuable forum for leading sanitary reformers such Drs Edward Swarbreck Hall, Gregory Sprott and J.S.C. Elkington, sanitary engineer Alfred Mault, statisticians E.C. Nowell and Bishop Bromby and the chemist W.F. Ward. The publication of the *Papers and Proceedings of the Royal Society of Tasmania* enabled sanitarians to present their arguments in some detail and these papers were often reprinted in the press. Drawing on developments in sanitary science in Britain, they argued that improving water supplies, drainage and sewage schemes, refuse removal and housing standards was the most effective way of lowering death rates and illness from diseases like typhoid and of making people healthier. Discussion in the Royal Society helped build momentum for public support of sanitary reform and was the clearest example of the Royal Society responding to a pressing community need. Despite complacency engendered by a salubrious climate, different views on the causes of disease, opposition to the pollution of waterways and reluctance by ratepayers and municipal councils to subsidise the cost of sanitary improvements, the sanitary reformers triumphed and municipal councils in Hobart and Launceston introduced a range of preventive health measures that contributed to the lowering of death rates by 1914 (Petrow 1995). Once sanitary improvements had been achieved and medical doctors formed their own association, papers on sanitary and medical subjects were rarely given but for nearly sixty years The Royal Society of Tasmania was the main forum for debate on public health reform.

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ANTARCTIC VIGNETTES VII: THE SEARCH FOR S. TASMAN – POSTSCRIPT

by Herbert J. G. Dartnall

(with three plates)

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Tasman Spaulding served as an Able Seaman on the S.Y. *Terra Nova* on the 1903–1904 voyage to Antarctica. A clerical error that reversed his given and family names meant he never knew of the bronze Polar Medal awarded for his services on the expedition. For the last 108 years the incorrectly named medal has languished in the archives of the Royal Mint in the United Kingdom but has been released for display at the Tasmanian Museum and Art Gallery in Hobart.

Key Words: Tasman Spaulding, S. Tasman, S.Y. *Terra Nova*, Polar Medal in bronze.

BACKGROUND

The *Terra Nova* arrived in Hobart on 31 October 1903. She had been sent by the Lords of the Admiralty under the command of Harry McKay with instructions to proceed to the Antarctic and rescue Captain Scott. Captain McKay was to extract Scott's ship, HMS *Discovery*, from the ice or, if that proved impossible, to abandon her and return home with Captain Scott and his men (Scott 1905, Savours1992).

Captain Scott's failure to send the research ship HMS *Discovery* back to Lyttelton as planned at the end of March 1903 had incurred the displeasure of the Lords of the Admiralty (Aldridge 1999). Charged with mounting a relief expedition the Admiralty bought the steam-powered wooden barque the *Terra Nova* from C.T. Bowring and Company Ltd of Liverpool for £20,000 and had her speedily re-rigged and made shipshape in Dundee (Jones 1973) and appointed Harry McKay her Master. McKay was probably the most experience ice-master and navigator then serving with the Arctic Whaling Fleet (Aldridge 1999).

Captain McKay assembled a crew of Dundee whalermen many of whom had served with him before. They were experienced seamen, hard men, many with a fondness for whisky (Jones 1973). The relief voyage was to be a dry one, and they might be away for several years so it is unsurprising that many turned up blind drunk when they were due to set sail. In the confusion one man, William Luke Ryan, went overboard and drowned whilst the ship was in the River Tay, while James Anderson immediately deserted. The *Terra Nova* had already sailed when he was caught and he was taken by the Royal Navy, under guard, to Aden where he was reunited with the *Terra Nova*.

The *Terra Nova* set sail on 21 August 1903 and arrived in Hobart 17 days ahead of schedule thanks to three Royal Navy ships that towed the ship at speed to a point just east of the Horn of Africa. HMS *Minerva* towed the *Terra Nova* from Portland to Gibraltar; HMS *Vindictive* towed through the Mediterranean with HMS *Fox* completing the section from Port Said down into the Indian Ocean (Jones 1973). After the tow was cast-off the *Terra Nova* made her own way to Hobart where she then spent the next five weeks, undergoing repairs, coaling and generally preparing for the voyage south.

Meanwhile many of the *Terra Nova*'s crew had a riotous time in Hobart. Nine sailors, at some time during their stay, went absent without leave, a relatively minor indiscretion, but two of these men compounded the offence by assaulting the police and were given custodial sentences of three and four months (BT100/50). Captain McKay discharged the major trouble maker, George Mitchell, but was now one seaman short. Just then Tasman James Spaulding, a local lad, was on the Hobart waterfront looking for a job (BT 100/50). At 23 he was an experienced seaman having rounded Cape Horn in square-riggers and he was quickly recruited (pl. 1). Six days later on 6 December 1903 the

PLATE 1
Tasman Spaulding A.B. on the Terra Nova.

PLATE 2
Tasman Spaulding's bronze Polar Medal. The image top left shows the medal's obverse. The image top right shows the medal's reverse; while the image at the bottom shows the naming round the edge of Tasman Spaulding's Polar Medal.

PLATE 3
Tasman Spaulding on the farm in later life.

SY *Morning* and the *Terra Nova* with Tasman Spaulding on board set sail. The two ships made good progress with the *Terra Nova,* the more powerful, invariably leading the way. When they arrived off Hut Point on 5 January 1904 nearly 20 miles (32 km) of solid pack-ice blocked their passage to HMS *Discovery* compared with the just 5 miles (8 km) that the *Morning*'s captain, Captain Colbeck had reported the previous March (Aldridge 1999). Over the next seven weeks the crews of the three ships nibbled away at the pack-ice. They cut channels with ice saws, and blasted the ice with charges of gun cotton while Captain McKay aboard the *Terra Nova* continually rammed the ice head-on. Progress was slow and right until the last possible moment it appeared that they would have to abandon the *Discovery* when a series of great ocean swells carried the last of the ice away and the *Discovery* was at last free.

The three ships then made their own way back to the United Kingdom via New Zealand. Tasman Spaulding disembarked at Lyttelton. On Captain Scott's return to the United Kingdom authority to grant the award of a medal akin to the Arctic Medals of 1818–1855 and 1875–1876 was sought. This was duly granted on14 September 1904 when the Polar Medal came in to being. Generally it was awarded in silver with a clasp inscribed ANTARCTIC 1902–04 to the officers, scientists and crew of HMS *Discovery*; and in bronze without a clasp, but with the years of service inscribed round the edge after the naming, to the officers and crew of the two relief ships (ADM 1/7848; Poulsom & Myres 2000).

TASMAN SPAULDING'S STORY

Thus Tasman Spaulding was awarded the King's Polar Medal in bronze (pl. 2) together with the rest of the *Terra Nova's* officers and crew whose work during the expedition was deemed satisfactory (ADM 171/61). Most of the medals to the men of the *Terra Nova* were presented by the Lord Provost, Dundee at a ceremony on 28 November 1906. Tasman Spaulding was of course living in Tasmania and his medal should have been posted to him. Unfortunately, despite clearly signing his name as Tasman Spaulding several times in the ship's log (BT 100/50) at some stage in the medal naming process Tasman Spaulding's given and family names were reversed and his medal was inscribed S. TASMAN "TERRA NOVA" 1903–4 instead of T. SPAULDING "TERRA NOVA" 1903–4 (pl. 2). Consequently when it came to send his medal, no one of the name S. Tasman could be found and the medal went unissued. Tasman Spaulding never learnt of his award. He married his childhood sweetheart in 1913 and settled down to a fishing and farming life style (pl. 3) in southeast Tasmania and died there in 1939 (Dartnall 2008).

TASMAN SPAULDING'S POLAR MEDAL

I have been interested in the men who took part in Antarctic Expeditions for a number of years and have visited Hobart several times in the course of my research. On one of these visits I decided to check Tasman Spaulding. He was of

particular interest as I believe he was the first Australian-born Australian to receive a Polar Medal. His birth, death and marriage records indicated that he had lived all his life in Dunalley (Dartnall 2008). On a subsequent visit to that hamlet I met up with Bill Dunbabin who as a boy had lived next door to Tasman Spaulding and his wife. Bill introduced me to George Whitehouse and Jim Spaulding — two of Tasman Spaulding's nephews — and my interviews of these three gentlemen formed the basis of my earlier paper on Tasman Spaulding (Dartnall 2008). Following the publication of that paper Rear Admiral J.A.L. Myres, C.B., then Secretary of the United Kingdom Polar Medal Assessment Committee took up the case. Admiral Myres confirmed the medal had never been issued and ascertained that since naming it had remained in the Royal Mint's archives. Enquiries were made and permission was granted for the medal to be made available. Sadly none of Tasman Spaulding's children lived more than a couple of months and he has no direct descendants. His Polar Medal has therefore been secured for display at the Tasmanian Museum and Art Gallery (TMAG) on a long term loan. The medal was presented to Sir Guy Green A.C., K.B.E., C.V.O., Chairman of the Board of Trustees and The Royal Society of Tasmania's nominee, on 20 June 2013 in the *Islands to Ice Gallery* TMAG where hopefully it will soon be on permanent display.

ACKNOWLEDGEMENTS

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A SIMPLIFIED INVENTORY APPROACH FOR ESTIMATING CARBON IN COARSE WOODY DEBRIS IN HIGH-BIOMASS FORESTS

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(with four tables and three text-figures)

Sohn, J., McElhinny, C., Grove, S., Hilbig, E. & Bauhus, J. 2013 (17:xii): A simplified inventory approach for estimating carbon in coarse woody debris in high-biomass forests. *Papers and Proceedings of the Royal Society of Tasmania* 147: 15–23. ISSN 0080-4703. Albert-Ludwigs-University Freiburg, Chair of Silviculture, Tennenbacherstr. 4, 79106 Freiburg, Germany (JS, EH, JB*); Australian National University, College of Science, The Fenner School of Environment and Society, Forestry Building 48, Linnaeus Way, Canberra ACT 0200, Australia (CM); Forestry Tasmania, 79 Melville Street, Hobart TAS 7000, Australia. Current address: Rosny Collections and Research Facility, Tasmanian Museum and Art Gallery, Rosny, TAS 7018, Australia (SG). *Author for correspondence. Email: juergen.bauhus@waldbau.uni-freiburg.de

Forests carrying large quantities of live and dead wood are important carbon (C) stores. Here, we investigate how the inventory of coarse woody debris (CWD) and its embedded C (CWD-C) may be designed efficiently at the scale of logs, plots, and the landscape in Tasmanian tall *Eucalyptus obliqua* forests, which have very high levels of CWD (here 375–1085 m^3 ha^{-1}). From a set of 12 sites representing different times since disturbance, a thorough census of dead wood >10 cm in diameter was carried out at five sites using a fixed-plot (50 × 50 m) approach. This showed that 90% of the volume can be captured by recording only CWD logs >40 cm in diameter. Based on this approach and on the known density and C content of five different decay-classes, volume, mass, and CWD-C was determined for all 12 sites. To obtain an accurate estimate of CWD-C at the landscape scale, it was found to be sufficient to allocate entire individual logs to single decay-classes and to use one global value for C content instead of decay-class-specific values. The most decayed logs, which are difficult to measure, could be ignored. However, at the plot level, no relationships were found between CWD mass and either standing or downed CWD or standing-tree biomass, limiting the utility of these proxies for assessing CWD volume.

Key Words: Coarse woody debris, monitoring, logs, decay-class, carbon.

INTRODUCTION

Coarse woody debris (CWD) comprises all aboveground dead woody biomass that exceeds certain thresholds in diameter and length. It includes standing (snags or stags), and downed boles (logs) and branches of dying and dead trees. Forests characterised by a high abundance and continuity of CWD are important carbon (C) stores and the CWD is important for a range of ecosystem functions. Research conducted over the last three decades has demonstrated that standing and downed CWD is a key structural and functional element of forest ecosystems (e.g., Harmon *et al.* 1986, Spies *et al.* 1988, Franklin *et al.* 2002, Siitonen 2001, Stewart & Burrows 1994, Carmona *et al.* 2002, Lindenmayer & Franklin 2002).

Increasing awareness of the significant role that dead wood plays for ecosystem functioning has led to the consideration of CWD in sustainable forest management worldwide (Bauhus *et al.* 2009, Hunter 1994, Grove 2002, Ranius *et al.* 2003, Lindenmayer *et al.* 2006). A common objective of the management of CWD is to maintain its spatial and temporal arrangement in a manner that mimics patterns caused by natural disturbance and stand development and provides for a continuity of habitat conditions (Franklin *et al.* 2002, Keeton 2006). To assign local benchmarks for CWD levels for certain forest types and to manage this pool, the natural variation of CWD attributes needs to be known and monitored. Inventories of CWD are also important for reporting of C storage in forests (Gough 2007).

In regions dominated by forests with relatively low amounts of CWD — for example boreal forests, forests of drier regions, or evergreen tropical forests — a full census of all types of CWD can be done relatively quickly using plot-based or line-intersect methods (e.g., Karjalainen & Kuuluvainen 2002, Woldendorp *et al.* 2004, Grove 2001). In contrast, in forest regions characterised by very high quantities of dead wood, inventory of all pieces of CWD across large areas or along numerous long lines are extremely time-consuming and expensive, and therefore impractical in most situations.

The main aim of this study was to examine whether it was possible to simplify the plot-based inventory of CWD and associated C in forests which carry large amounts of dead wood such as the Tasmanian tall wet eucalypt forests (Woldendorp *et al.* 2004) by identifying the CWD attributes that should be measured and those that may not have to be quantified. In particular, the study asked whether for estimating CWD volume, biomass and C content:

- it is possible to concentrate the inventory on larger CWD piece;
- it is sufficient to allocate individual logs to the dominating (in terms of volume) decay-class of that log to calculate its average mass and C density;
- one needs to also capture the most advanced decay stage, which is always difficult to quantify in terms of volume and mass and
- volumes of both standing living and dead trees available from many inventories may be used to predict the volume of downed logs.

To answer these questions, we first quantified all types of CWD with a diameter greater than 10 cm in five 0.25 ha plots located in tall wet *Eucalyptus obliqua* (L'Hérit.) stands of different disturbance history and age. We investigated the frequency of a range of CWD attributes and the relationships among them in order to identify key parameters and to determine appropriate minimum diameter-thresholds. Second, these results were applied for sampling seven additional *E. obliqua* stands, which were comparable in age and origin to those assessed before, in

order to capture the variation in CWD and C more widely in the same landscape.

METHODS

Study region and forest dynamics

The study was conducted at the Warra Long Term Ecological Research (LTER) site (Brown *et al.* 2001) in southern Tasmania, Australia (latitude 43° S, longitude 147° E). The climate at Warra is temperate maritime with a mean annual temperature of 7.9 °C, and an annual precipitation of 1477 mm. The region is characterised by mountainous terrain with peaks up to 1200 m above sea level. The geology is Jurassic dolerite, which produces fertile, deep clay soils (Turner *et al.* 2007).

The vegetation of this region is southern cool temperate wet forest. Wildfires, with return intervals of 100–400 years, lead to the predominance of tall wet *E. obliqua* forests. This forest type is characterised by a tall (>30 m), open (projective foliage cover 30–70 %) eucalypt overstorey, dominated by *E. obliqua* and some admixed *E. regnans* (F. Muell) or *E. delegatensis* (R. Baker). On fertile, protected sites, old trees reach more than 55 m in height, in rare cases over 80 or 90 m (Hickey *et al.* 2000). The understorey can be variable in density and composition, and contains numerous sclerophyll species such as *Acacia* spp., *Anopterus glandulosus* Labill., *Clematis aristata* R. Br. ex Ker Gawler, *Cyathodes glauca* Labill., *Monotoca glauca* (Labill.) Druce, *Nematolepis squamea* (Labill.) Paul G. Wilson, *Olearia argophylla* (Labill.) Benth., *Pimelea linifolia linifolia* Smith, *Pomaderris apetala* Labill. and *Tasmannia lanceolata* (Poiret) A.C. Smith.

If fire intervals exceed 100 years, mixed forests with tall eucalypt emergents above a rainforest midstorey containing (*Nothofagus cunninghamii* (Hook.) Oersted, *Atherosperma moschatum* Labill., *Eucryphia lucida* (Labill.) Baill. and *Phyllocladus aspleniifolius* (Labill.) Rich. ex Hook. f.) will replace pure eucalypt stands. In the absence of fires for more than 350–400 years, the flammable eucalypt overstorey dies out and a much less flammable rainforest persists (Wells & Hickey 2005).

Study plots

Measurements were carried out in twelve permanent plots, which had been established as part of a "wildfire chronosequence project" in the Warra region (Turner *et al.*

TABLE 1
Origin, density and composition of the twelve plots of the Warra wildfire chronosequence project measured in this study

Plot	Origin	Basal area (m^2 ha^{-1}) of living trees >10 cm	Proportion of total basal area by genus (%) [1]	CWD volume (m^3 ha) of logs and stags >40 cm diameter (logs and stags >10 cm)
OGS	Undated wildfire before 1898	117.3	*Eucalyptus* sp. (40), *Nothofagus cunninghamii* (20), *Atherosperma moschatum* (15), *Dicksonia antarctica* (20)	851 (1005)
OGN		126.1	*Eucalyptus* sp. (75), *Eucryphia lucida* (10), *Phyllocladus aspleniifolius* (5)	922
1898S	Wildfire in 1898 and partly burned in1934	91.6	*Eucalyptus* sp. (75), Pomaderris apetala (15)	299 (351)
1898N		71.2	*Eucalyptus* sp. (80), *Pomaderris apetala* (15)	806
1934S	Wildfire in 1934	118.9	*Eucalyptus* sp. (70), *Dicksonia antarctica* (15)	477 (558)
1934N		71.3	*Eucalyptus* sp. (85), *Pomaderris apetala* (10)	998
1966S	Wildfire in 1966	44.0	*Eucalyptus* sp. (95)	464 (559)
1966N		51.4	*Eucalyptus* sp. (50), *Acacia dealbata* (10), *Dicksonia antarctica* (20), *Pomaderris apetala* (20)	1410
1967CS	Clearfell-burn-sow in 1967	46.2	*Eucalyptus* sp. (85), *Acacia dealbata* (5)	1001 (1176)
1967CN		59.3	*Eucalyptus* sp. (90), *Acacia dealbata* (5)	1006
2001CS	Clearfell-burn-sow in 2001 resp. 2003	0.0	N/a	403
2003CN		0.2	N/a	680

The fourth column shows the proportion (rounded to nearest 5 %) of total basal area for each tree genus contributing at least 5 %. Plots in bold letters (first column) belonged to the first measuring campaign (= full-census). For all twelve plots, CWD volume of logs and stags > 40 cm is shown (last column). Additionally, for the five full-census plots, CWD volume of logs and stags > 10 cm is depicted (last column number in brackets). S=south facing, N=north facing slopes, OG=undated old-growth.

2007) (table 1). Sites were selected to represent comparable environments. They were situated 120–280 m above sea level on mid-slopes. Eight of the twelve plots were wildfire-derived, with four being located on south-facing (S) and four on north-facing (N) slopes (table 1, Turner *et al.* 2007). These eight sites had no history of active forest management and represented different-aged ("regrowth") stands that initiated following wildfire disturbance in 1966 (referred to as 1966S and 1966N), 1934 (referred to as 1934S and 1934N), 1898 (referred to as 1898S and 1898N), and an undated fire before 1898 (referred to as old-growth = OGS and OGN). Even though the 1898 stands are ostensibly derived from a wildfire in 1898, elements of their stand structure and tree species composition indicate that they were also partially burnt in 1934.

The remaining four sites were stands regenerated following clearfelling and a regeneration burn and sowing of eucalypts. Again two were located on south-facing and two on north-facing slopes. Two of these plots were harvested in 1966 (referred to as 1966CS and 1966CN), one in 2001 (referred to as 2001CS) and the fourth in 2003 (referred to as 2003CN) (Turner *et al.* 2007).

Field measurements and calculation of secondary attributes

Each plot comprised a 50 × 50 m (0.25 ha) quadrat, divided into 25 subplots of 10 × 10 m (Turner *et al.* 2007). In the first measuring campaign, each piece of standing and downed dead wood >10 cm in diameter and >1 m in length present in the plot was assessed at five sites (table 1 plots in bold letters). Based on the results from the first measuring campaign, the original inventory protocol was modified so that in the seven remaining plots only logs larger than 40 cm diameter were measured during a second field campaign. However, for standing dead wood, we still used the 10 cm diameter threshold.

The following measurements were made: CWD type (snag/log/branch; the latter only if not attached to boles any longer, or if unclear "unidentified"), species (if identifiable), horizontal (width) and vertical (depth) diameter at each end of the piece; length; decay-class (using a five-class system described in Grove *et al.* (2009). For the logs of the second campaign, multiple decay-classes were still recorded for each piece of dead wood, since it was not known what effect a simplified reporting of one decay-class per log would have had on mass and C content, which can vary considerably with decay-class and rot type in these forests (Grove *et al.* 2009).

For standing CWD, only diameter at breast height (1.3 m) and total height were recorded. These attributes represented the most frequently measured parameters in previous studies of CWD (e.g,. Spies *et al.* 1988, Stewart & Burrows 1994, Harmon & Sexton 1996, McKenny & Kirkpatrick 1999, Carmona *et al.* 2002, Pedlar *et al.* 2002, McElhinny *et al.* 2006).

Measurements took place at the level of log-segments, in which pieces of CWD were divided whenever they showed a change in decay-class or crossed a subplot boundary. The following secondary attributes were derived from the directly measured attributes:

Log or branch volume V (m^3) was derived using Smalian's formula as suggested by Harmon *et al.* (1986):

$$V = \left(\frac{(a_1 + a_2)}{2}\right) \times l \qquad \text{eq. 1}$$

where a_1 and a_2 are the cross-sectional areas (m^2) of each end and l is the length (m) of the CWD piece or sub-segment.

Snag volume V_s (m^3) was derived using a taper function for *E. obliqua* (Private Forests Tasmania 2001):

$$V_s = \frac{0.2 \times dbh^2 \times h}{10000} \qquad \text{eq. 2}$$

where *dbh* is the diameter at breast height (cm) and h the height (m).

Decay-class diversity (D^*) within each log was derived using the Shannon-Weaver Index (Krebs 1989):

$$D^* = -\sum_{i=1}^{S} p_i \ln p_i \qquad \text{eq. 3}$$

where S is the number of decay-classes present in a log, and p_i the proportion of volume in a given decay-class.

To calculate the carbon stock in CWD of each plot, we calculated first the CWD volume of each decay-class separately. Volumes in each decay-class were multiplied by values of CWD density in the different decay-classes of CWD, which had been determined for this forest type (DC1= 495.25 kg m^{-3}, DC2= 439.41 kg m^{-3}, DC3= 378.96 kg m^{-3}, DC4=291.67 kg m^{-3}, and DC5= 212.17 kg m^{-3}) (Grove *et al.* 2009). These values are based on the calculations of average distribution of rotten-wood types and associated densities for each decay-class (see Grove *et al.* 2009). The resulting values for biomass of logs in each of the five decay-classes were multiplied by 0.5 to yield the C-content of CWD. This simple conversion could be done as C-content of CWD biomass is generally about 50 % and remains largely unaffected by decay-state in *E. obliqua* (Grove *et al.* 2009).

Data analysis

The measured and calculated attributes of log-segments were pooled for analyses at the scale of whole logs in order to detect relationships among attributes and variation among individual logs. Correlation matrices containing the measured and derived variables were used to identify possible relationships. Pearson correlation coefficients (r) were used to assess correlations among all possible combinations of log attributes. R-values between 0.5 and 0.8 were considered to be moderately correlated, and r-values >0.8 to be highly correlated. To examine relationships for moderately and highly correlated variables further, regression analysis was used.

The effect of different minimum diameter-thresholds of logs measured (10 to 100 cm in 10 cm steps) on the proportions of the total number of logs and total CWD volume captured was assessed for the five full-census plots.

As recording decay-class composition of logs can be a relatively complex procedure and relies on subjective visual estimation of decay-classes of log segments, we investigated how this can be done more efficiently. First we examined the possible overestimation or underestimation of decay-

class-specific CWD volume associated with assigning a single decay-class to individual logs instead of multiple decay-classes as was done during our first measuring campaign. This was done for each of the five full-census plots and separately for all logs and for small logs only (<40 cm diameter).

Next, we checked the accuracy of carbon calculations when using only one average value for converting volume into biomass density instead of decay-class specific values for density of CWD. For this purpose, CWD-C in each of the twelve plots (calculated as described above) was compared with a value obtained by multiplying plot volume by the C-density of decay-class 3, which was the most abundant with regards to volume.

Determination of living stem biomass

In a preceding inventory, the DBH of all live stems >10 cm DBH (diameter at breast height above bark) had been recorded to the nearest cm, and the species determined. Height to top of crown was measured for a representative sample of trees for each major species. These height data were used to assign mean dominant height values for each species in each plot. We used a package of programs (Farm Forestry Toolbox, Private Forests Tasmania 2001) to calculate plot-level basal area and total stem volume.

RESULTS

Monitoring at the scale of CWD pieces

The volume of total (downed and standing) CWD >10 cm ranged between 350 and 1175 m^3 ha^{-1} among the first five plots (table 1, right column numbers in parentheses). The bulk of this (87%) occurred as downed rather than standing CWD (13%). Branches comprised about 25% of all measured pieces of CWD but contained only about 5 % of the total CWD volume (table 2). Increasing the minimum diameter-thresholds for inventory of CWD showed that the number of pieces to be measured dropped off much more rapidly than the volume of CWD captured at the same time (fig. 1).

Logs had a significantly higher decay-class diversity index than branches (table 2). There were significant ($p<0.01$), although weak, correlations between decay-class diversity and measures of CWD size. The strongest correlation ($r=0.41$, results not shown) was between decay-class diversity and CWD length, indicating that longer pieces of CWD were more likely to contain sections in different decay-classes. The correlations between decay-class diversity and CWD volume and CWD mean diameter were weak ($r = 0.29$ and $r = 0.24$, respectively, results not shown). Ninety-two percent of CWD pieces showed no change in decay-class along their length; for logs <40 cm mean diameter this value increased to 94 %.

Assigning entire logs only to the volumetrically dominant decay-class instead of multiple classes led to deviations of up to 15 % of CWD volume at the level of individual plots (50 × 50 m) (decay-class 3 in the old-growth stand, table 3a). However, if only considering logs <40 cm for single decay-class classifications while still using multiple decay-classes for logs >40 cm, the maximum error was considerably smaller at only 2.7 % (decay-class 4 in the 1967 clearfelling plot, table 3b). The deviations caused by assigning only on decay class to logs were not systematic.

Monitoring at plot- and landscape-scales

During the second measurement campaign, attributes of 255 logs with a mean diameter >40 cm were measured in seven additional plots of wet *E. obliqua* forest (table 1, plot names in bold letters). The following results are based on analyses of attributes of these logs and the additional 128 logs >40 cm diameter which had been recorded in the five plots of the first, intensive measurement campaign.

TABLE 2
Mean and range (in brackets) of diameter, length, volume, and decay-class diversity index for 848 logs and 248 branches and the number of plant species (ferns and vascular plants) present on them in five *Eucalyptus obliqua* stands ranging in age from 41 to >110 yrs

Attribute	Logs	Branches
Diameter (cm)	25.5[1] (5.7[2]–213.8)	20.5[1] (8.4–58.1)
Length (m)	4.2[1] (1.0–56.6)	3.2[1] (1.0–27.0)
Volume (m^3)	0.89[1] (0.004–52.4)	0.15[1] (0.007–2.2)
Decay-class diversity index	0.05[1] (0–1.05)	0.03[1] (0–0.70)
Number of ferns and vascular plant species	1.3[1] (0–11)	0.1[1] (0–7)
Proportion of total CWD volume (%)[3]	94.8	4.8
Proportion of total number of CWD pieces (%)	75	25

[1] indicates a significant difference between values ($P<0.05$).
[2] Value could be <10 cm because the CWD threshold of 10 cm applied only for measuring width and not for depth. Diameter was calculated as the geometric mean of width and depth.
[3] The proportions of log and branch volumes amount to less than 100% as some pieces of CWD could not be classified as a log or a branch.

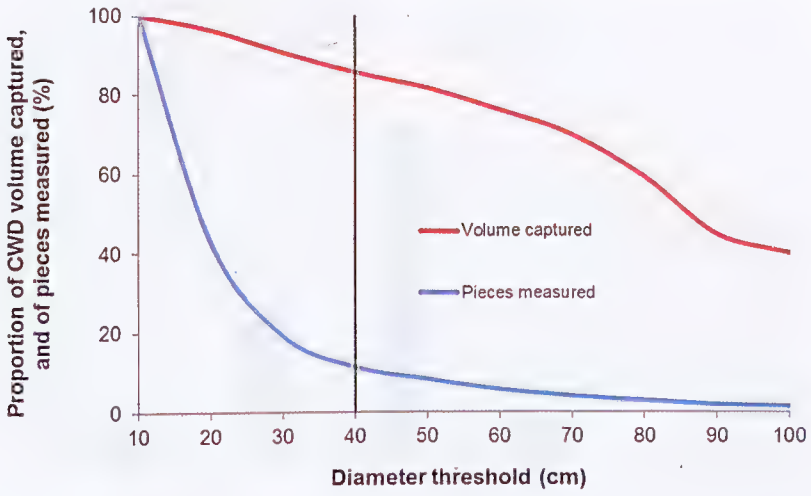

FIG. 1 — Proportion of total number of logs and branches measured and proportion of total CWD volume captured for different diameter measurement-thresholds. The grey vertical line displays a diameter threshold of 40 cm, which was used during our second measuring campaign. (N=1096, which includes all logs and branches >10 cm measured in the five plots of the first campaign.)

TABLE 3
Over- or underestimation of percentage of CWD volume in each decay-class per plot, when assigning a single decay-class rather than multiple decay-classes to (a) all logs, and (b) logs with a diameter of <40 cm only. For a given piece of CWD the decay-class containing the greatest proportion of volume was allocated to that piece.

Plot	Deviation (%) from real CWD volume in decay-class				
	1	2	3	4	5
(a) All logs					
OGS	0.0	-0.0	15.0	-8.1	-6.9
1898S	0.0	-0.1	3.0	1.1	-4.1
1934S	0.7	0.1	-2.6	-0.9	3.4
1966S	0.0	10.4	-12.6	2.5	-0.3
1967CS	0.0	-4.0	7.6	-3.2	-0.4
(b) Logs <40 cm diameter only					
OGS	0.0	-0.2	-0.5	2.4	-1.7
1898S	0.0	-0.3	1.5	0.6	-1.8
1934S	0.4	0.7	1.1	-2.1	0.0
1966S	0.0	-1.2	2.4	-0.6	-0.6
1967CS	0.0	-0.1	-2.7	2.7	0.0

The proportion of log volume in different decay-classes varied considerably. Relatively small values were measured in three out of five decay-classes (0.3 % in DC1, ca. 6 % in DC5, and ca. 8 % in DC 2, fig. 2), while the remaining two decay-classes accounted for the bulk of log volume with ca. 59 % of CWD volume contained in DC3 and 27 % in DC4 (fig. 2). We now analysed the effect of assigning a single instead of multiple decay-classes to individual logs for all logs (N= 383) across twelve plots (= 3 ha). This led to only minor deviations (–2.6 % to + 3.3 %) from actual CWD volume per ha within different decay-classes at this larger spatial scale (fig. 2).

The estimated amount of plot-based C present in CWD logs >40 cm ranged from 52.9 to 183.0 Mg ha^{-1} and was on average 119.4 Mg ha^{-1} across the twelve plots (table 4). To explore further simplifications, we investigated the

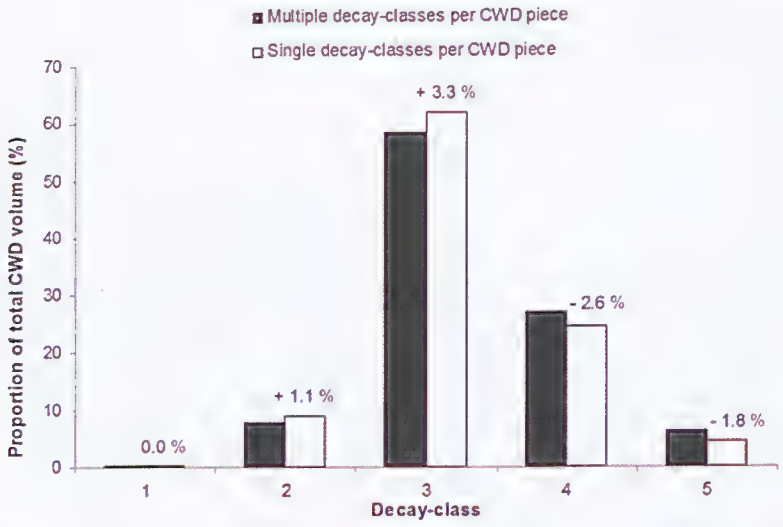

FIG. 2 — Proportion of total CWD volume per ha in different decay-classes, if assigning logs to multiple or single decay-classes. For a given piece of CWD the decay-class containing the greatest proportion of volume was allocated to that piece. Values refer to logs >40 cm which were measured in twelve Eucalyptus obliqua *stands. For each decay-class the over- or underestimation of actual volume is presented as percent error (%), N= 383.*

TABLE 4
Carbon mass (Mg ha^{-1}) of large logs (>40 cm mean diameter) in twelve plots of tall wet *Eucalyptus obliqua* forests and mean across all plots, and deviations (%) from these values if only one average value for wood density is used, or if logs of the most advanced decay-class (DC5) are disregarded.

Plots	C (Mg ha^{-1}) in logs >40 cm mean diameter	Deviations if considering density of DC3 only (%)	Underestimations if disregarding DC5 in inventory (%)
OGS	133.5	5.2	–12.0
OGN	160.9	4.1	–8.6
1898S	52.9	2.2	–4.6
1898N	142.8	3.1	–9.9
1934S	88.7	–2.2	–4.5
1934N	117.8	–1.4	–7.0
1966S	60.1	–5.4	–0.7
1966N	152.1	–1.7	–2.1
1967CS	183. 0	–3.6	–0.3
1967CN	139.8	–3.7	–0.2
2001CS	67.1	–9.1	–5.4
2003CN	134.0	–7.5	0.0
Mean of all plots	119.4	–1.3	–4.7

effect of using only one average wood density — that of the most abundant decay-class (DC 3) — instead of five different decay-class-specific values for calculating CWD-C. This approach led to deviations between –9.1 and +5.2 % for individual plots (table 4). However, if we regard the plots as independent samples for the landscape dominated by this forest type, the total error would be small (–1.3 %) at the landscape scale (table 4, last row). An additional analysis showed that ignoring logs of the most advanced decay-class (DC5) during field measurements would lead to relatively small underestimations (<5 %) of total CWD-C at the landscape scale (table 4).

The assessment of the potential to predict CWD mass from information that can be remotely sensed showed that no correlation could be detected between the stem volume of live trees and the CWD volume across the twelve plots (fig. 3, r=–0.009, N=12).

DISCUSSION

Implications for monitoring at the scale of logs

The results of the full census indicated that 95% of CWD volume in these forests is in logs, and that large logs account for the bulk of this (table 2, fig. 1). Therefore, the number of pieces to be measured can be reduced drastically with little underestimation of the total CWD volume (fig. 1). Based on our results, the exclusion of logs smaller than 40 cm in diameter from inventory means that the remaining number of logs to be measured would amount only to ca. 10 % of all logs, whilst still capturing ca. 90 % of the total CWD volume.

However, when considering a diameter threshold for monitoring CWD volume, mass, or carbon, it is important to consider that trees can develop internal hollows while they are alive (Williams & Faunt 1997), as was the case for our study sites. These hollows or "pipes" in eucalypt stems must be subtracted from the true CWD volume or mass. If the average degree of piping in CWD is known, then a diameter threshold can be used to compensate for the overestimation of volume induced by piping. Working in the same study-area, Stamm (2006) reported that *E. obliqua* logs across all decay-classes have an average internal airspace equivalent to 20–30 % of the original volume. Assuming that logs derived from other species show similar piping to *E. obliqua*, or, more realistically, that all larger-diameter logs in a typical stand are derived from *E. obliqua*, then selecting a diameter threshold of 50–70 cm would balance losses due to piping and yet would require only 5–10 % of logs to be measured (fig. 1). Obviously, these thresholds are not transferable and would have to be determined for other high biomass forests.

We found that for estimating total C and volume in CWD, branches and small logs did not need to be measured in these forests. However, this may not be appropriate for studies investigating other attributes and functions of CWD that are particularly associated with these types of CWD, e.g., the presence of certain saproxylic species (Grove 2002).

Implications for inventorying CWD at the landscape scale

Although assigning large logs to only one decay-class per log would lead to considerable errors for calculating CWD volume by decay-class at smaller spatial scales (i.e., the fixed-area plots), at the landscape scale this simplification resulted in accurate estimates of CWD volume distribution over decay-classes (fig. 2). Further, at the landscape scale, CWD-C mass was underestimated by only about 1 % when using one average value of wood density instead of decay-class specific ones (table 4).

Using this approach for inventory of CWD-C in forests dominated by large, long logs would present a significant simplification as assigning log segments to different decay-classes is time-consuming and also a considerable source of error due to subjectivity during decay-class classifications.

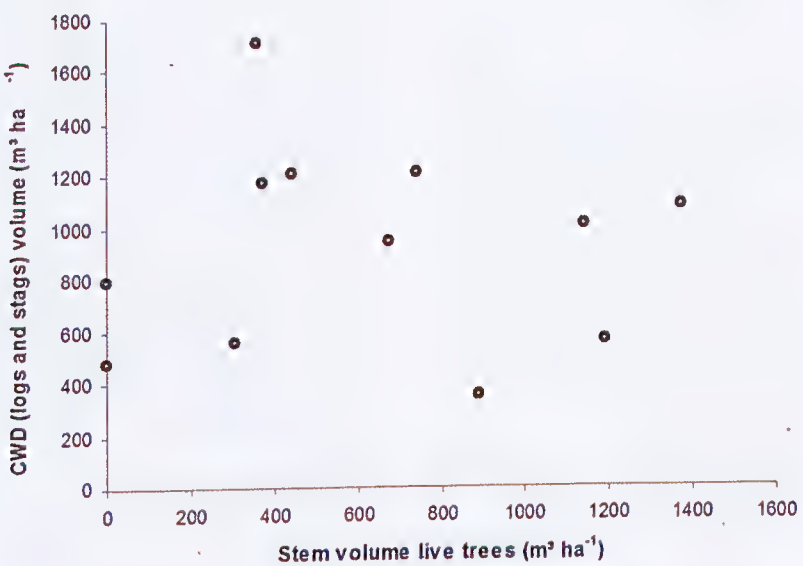

FIG. 3 — Relationship between CWD volume and stem volume of living trees in 12 different-aged Eucalyptus obliqua *stands.*

However, this simplification may not be appropriate to estimate landscape-level CWD-C in situations with a more even distribution of CWD volumes across decay classes or where the decay-class with average C density is not also the most abundant, as was the case here with decay-class 3.

Owing to the fact that decay-class 5 had the lowest carbon density (0.15 Mg m^{-3}) and comprised only a low volume in these forests, not recording logs of decay-class 5 led to only small underestimation (<5 %) of actual carbon mass (table 4). Ignoring logs of DC5 may be especially promising for increasing efficiency of CWD assessments as logs belonging to this decay-stage are the most difficult to measure. Many of these logs have largely disintegrated, lost their original shape, and are often not visible beneath thick moss covers and root systems. However, the decision not to record this decay-class should be based on the assessment of its contribution to the total CWD volume, which may be higher in other forest types, i.e., temperate forests of Patagonia, Chile (Carmona *et al.* 2002).

Ranius & Kindvall (2004) modelled the amount of CWD present in the landscape based on the relationship between the volumes of living trees and CWD for the mixed coniferous forests of boreal Sweden. Identifying this kind of relationship may be possible in forests in which the creation of dead wood is largely a function of self-thinning and small-scale disturbances. However, in the wet *E. obliqua* forests of southern Tasmania, biomass of living trees was not a good indicator for volume or mass of CWD probably due to the variable disturbance intensity in the wet *E. obliqua* forests and the longevity of both standing and downed trees. Therefore, it would be highly unlikely that amounts of CWD would ever be in equilibrium with living biomass. A low correlation between variables of downed CWD and living-tree characteristics was also found in boreal conservation forests in Eastern Finland (Pesonen *et al.* 2008). In addition, close relationships between living and dead woody biomass would also not agree with the temporal patterns of dead wood stocks following intensive disturbances as proposed by Harmon (2009).

CONCLUSIONS

Results from this study offer opportunities to increase the efficiency of CWD inventories for forests with high stocks of dead wood, as characteristically occur in forest ecosystems shaped by catastrophic disturbances and/or are characterised by slow decomposition rates. In addition to the tall wet eucalypt forest, this might apply also to coniferous forests in the Pacific Northwest of the US (e.g., Spies *et al.* 1988, Harmon *et al.* 1986) and the *Nothofagus* forests of New Zealand (Stewart & Burrows 1994) and southern Chile (Carmona *et al.* 2002, Schlegel & Donoso 2008).

For CWD biomass and carbon inventories in these types of forests, we recommend the following:

1. At any spatial scale:

- determine a minimum diameter-threshold to avoid sampling of many small CWD pieces.

2. For landscape surveys only:

- assign each CWD piece to a single decay-class and explore the use of a single density-value to convert volume to mass and C content,
- assess the effect of disregarding logs of the most advanced decay stage.

Our study was based on a plot-based approach, including a full census of CWD pieces with a diameter >10 cm in each plot. This type of CWD inventory is often associated with regular grid- and plot-based forest inventories in which many other forest attributes are measured. Alternatively, sampling of downed CWD could be carried out with line intersect transects (Warren & Olsen 1964, Van Wagner 1968), which have been shown to be more efficient in comparison with plot-based methods for *Eucalyptus*-dominated forests with a canopy cover of >50 % (Woldendorp *et al.* 2005). Our recommendations may be combined with the line intersect sampling approach. This might assist in determining variation of CWD attributes at the scale of forest landscapes, for which we are currently lacking information (e.g., Kennedy & Spies 2007).

The recommendation to avoid measuring small diameter material CWD must be seen in the context of inventories of CWD volume and C. In fire-prone forest ecosystems, small-diameter woody litter may well be a valid focus of inventories because it contributes to the fuel hazard. The same may be said about special habitat that is provided by accumulations of small woody debris.

The results of our study emphasised the importance of recording downed CWD separately rather than using readily available data on vertical structure (.i,e. standing dead or living trees) as a proxy for estimating log volume. Owing to their tall, dense and evergreen canopies, the latter is scarcely assessable through remote sensing in tall wet eucalypt stands. However, in other forests, where density of canopy, sub-canopy and shrub and understorey layer permit, airborne laser-scanning maybe promising for the assessment of downed CWD (Naesset 2007, Pesonen *et al.* 2008).

ACKNOWLEDGEMENTS

A Tribute to Chris McElhinny

This contribution is dedicated to Chris McElhinny, Senior Lecturer in Forest Ecology and Silviculture, who died before this paper could be published. Chris was fascinated by the structure and complexity of forests, in particular by tall wet eucalypt forests, and he made important contributions to their analysis and sustainable management. His fascination for the topic, his creative analyses and his dedication to responsible solutions for the management of Australia's forests inspired his colleagues and students alike. He will be deeply missed by us.

We greatly appreciate the use of the "Wildfire Chronosequence Project" plots at Warra that have been set up by P. Turner and co-workers. Julia Sohn and Eva Hilbig received a Warra small projects grant from Forestry Tasmania (FT), who also provided technical and organisational support. We are grateful for field assistance by Craig Airey (FT) and many others.

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(accepted 1 October 2013)

PYGMY SPERM WHALE (*KOGIA BREVICEPS*) STRANDING RECORD IN TASMANIA, AUSTRALIA, AND DIET OF A SINGLE SPECIMEN

by Isabel Beasley, Yves Cherel, Sue Robinson, Emma Betty and Rosemary Gales

(with two text-figures, one plate, three tables and an appendix)

Beasley, I., Cherel, Y., Robinson, S., Betty, E. & Gales, R. 2013 (17:xii): Pygmy Sperm Whale (*Kogia breviceps*) stranding record in Tasmania, Australia, and diet of a single specimen. *Papers and Proceedings of the Royal Society of Tasmania* 147: 25–32. ISSN 0080-4703. School of Earth and Environmental Sciences, James Cook University, Townsville, Queensland 4811, Australia (IB*); Centre d'Etudes Biologiques de Chizé, France (YC); Invasive Species Branch, Department of Primary Industries, Parks, Water and Environment, GPO Box 44 Hobart, Tasmania 7001, Australia (SR); Institute for Applied Ecology New Zealand, School of Applied Sciences, Auckland University of Technology, New Zealand (EB); Biodiversity Conservation Branch, Department of Primary Industries, Parks, Water and Environment, GPO Box 44 Hobart, Tasmania, 7001 Australia (RG). *Author for correspondence. Email: Isabel.Beasley@jcu.edu.au

This study describes the stranding record of the Pygmy Sperm Whale, *Kogia breviceps*, in Tasmanian waters, and the diet of a single individual. The Pygmy Sperm Whale is one of the most commonly stranded cetaceans in some parts of Australia, although it occurs infrequently in the Tasmanian stranding record, with only seven known stranding events. Dietary items were investigated from a single juvenile male Pygmy Sperm Whale stranded in southeast Tasmania. The recoverable diet consisted of approximately three kilograms of reconstructed cephalopod prey mass from at least 11 cephalopod species within nine families. Using reconstructed biomass, the most important family was Histioteuthidae (*Histioteuthis atlantica* and *H. miranda*: 29% of reconstructed biomass), followed by Ommastrephidae (unknown sp.: 27% of reconstructed biomass), Enoploteuthidae (*Enoploteuthis* sp): 25% of reconstructed biomass), Cranchiidae (*Cranchia scabra* and *Teuthowenia pellucida*), Chiroteuthidae (*Chiroteuthis veranyi*), Brachioteuthidae (*Brachioteuthis linkovskyi*), Neoteuthidae (*Nototeuthis dimegacotyle*), Pyroteuthidae (*Pyroteuthis margaritifera*) and Sepiolidae (*Heteroteuthis* sp.). Collection and analysis of biological material from Pygmy Sperm Whale strandings around Australia should be a high priority to better understand the ecology of this poorly known species.
Key Words: Pygmy Sperm Whale, *Kogia breviceps*, diet, cephalopods, Tasmania, Australia.

INTRODUCTION

The Pygmy Sperm Whale, *Kogia breviceps* (Blainville, 1838) is one of the least understood of all cetaceans that frequent Australian waters. This oceanic species is widely distributed in tropical and temperate waters of the Atlantic, Pacific and Indian oceans (McAlpine 2002); however, it is elusive and rarely sighted at sea.

There are only two known reported sightings of Pygmy Sperm Whales in Australian waters (DEWHA 2011), so that much of what is known about the occurrence of this small cetacean is obtained through stranding records. Stranded Pygmy Sperm Whales have been recorded from all Australian states but not the Northern Territory, with 24 stranding events (up to 2011) reported from Queensland (Strandnet, Department of Environment and Heritage Protection, records from 1932–2011); 16 strandings (up to 2008) reported from Victoria (K. Greengrass, Department of Sustainability and Environment, pers. comm.); 40 stranding events reported from South Australia (Kemper & Ling 1991, Kemper unpubl. data); and 18 strandings (from 1981–2010) recorded from Western Australia (Groom & Coughran 2012). No information was available for New South Wales.

Despite these strandings, few published data exist regarding Pygmy Sperm Whale morphometrics, biology or diet from Australian waters. Information on Pygmy Sperm Whale diet is available from only three studies in the Australian/Tasman region: Hale (1947) and Plön (2004) in Australia and Beatson (2007) in New Zealand. Hale (1947) described fragments of prawns from the genera *Peneus* (Family Peneidae) and *Hymenodora* (Family Oplophoridae) obtained from the stomach of an adult female that stranded at Port Victoria in 1937, and several cephalopod beaks (*Sepioteuthis australis* Quoy & Gaimard, 1832) from the stomach of her calf, which was apparently also still suckling. Plön (2004) investigated the natural history of *Kogia* sp. off Southern Africa, where samples from four South Australian animals were compared to Southern Africa animals. Plön (2004) found remains of the crustacean *Neognathauphausia ingens* Dohrn, 1870, as well as large quantities of Octopodidae, Enoploteuthidae, Histioteuthidae and Ommastrephidae (i.e., >20% mass/individual), and smaller quantities of Chiroteuthidae, Octopoteuthidae, Ommastrephidae and Mastigoteuthidae (i.e., <20% mass/individual). Beatson (2007) investigated Pygmy Sperm Whale diet from 27 stranded individuals in New Zealand, where Pygmy Sperm Whales are one of the most frequently stranded cetacean species. Beatson (2007) found that the diet consisted primarily of mesopelagic cephalopods (23 species from 13 families, dominated by juvenile individuals of the families Histioteuthidae and Cranchiidae), with some fish and crustacean remains also present.

Investigations of diet are particularly important for cetacean species not commonly observed at sea, such as the Pygmy Sperm Whale. Dietary information can assist in determining habitat use, foraging behaviour, preferred prey, and in assessing any direct or indirect interactions with fishery operations. This study presents the first detailed qualitative and quantitative assessment of diet for this little-known species in Australian waters.

MATERIALS AND METHODS

Pygmy Sperm Whale occurrence records around Tasmania from 1989–2009 were compiled using data obtained from the Department of Primary Industries, Parks, Water and Environment (DPIPWE) Tasmania, and Tasmanian Museum and Art Gallery (TMAG) records.

On 17 February 2003, two Pygmy Sperm Whales (one juvenile male with total length of 200 cm; and one juvenile female with total length of 215 cm) were found dead on Carlton Beach, southeast Tasmania (pl. 1). We classified these individuals as "juveniles" (i.e., not sexually or physically mature) based on Plön (2004: pp. 9–19), who found that for South African Pygmy Sperm Whales, males reach sexual maturity between 241–242 cm and females at 262 cm. Morphometric data, tissue and organ samples and stomachs were collected from the deceased whales, following the protocols of Geraci & Lounsbury (2005). Samples were stored at –20°C until analysed.

The stomach contents were subsequently thawed, rinsed through a 1.0 mm sieve and sorted. Cephalopod remains and parasites, when present, were preserved in 70% ethanol. Cephalopod beaks were separated from other cephalopod hard-part remains and sorted into upper and lower beaks. The lower beaks were identified to the lowest possible taxonomic level with the aid of cephalopod reference collections held at the Centre d'Etudes Biologiques de Chizé, France (identified by Drs Yves Cherel [YC] and Jose Xavier [JX]); Auckland University of Technology's reference collection of beaks extracted from entire, identified squid and octopus from New Zealand waters (identified by Dr Steve O'Shea [SO] and Emma Betty [EB]); and a cephalopod beak reference collection developed by Evans & Hindell (2004), currently housed at the University of Tasmania, Hobart. All identified beaks from this study are housed at the Tasmanian Museum and Art Gallery.

To estimate the original size of the cephalopod prey, lower rostral lengths (LRLs) for squid, and lower hood lengths (LHLs) for sepiolids, were measured with digital callipers to the nearest 0.1 mm, and regression equations were used as constructed by Clarke (1980, 1986), Rodhouse *et al.* (1990), Piatkowski *et al.* (2001), and Lu & Ickeringill (2002) (appendix 1). The total number of individuals of each cephalopod species present in a stomach was estimated based on the number of lower beaks, as in many cases the upper beaks were unidentifiable. The relative importance of prey items was quantified by (1) proportion of numerical abundance (% Num), the percentage of the total number of prey items represented by a particular prey category; and (2) proportion of reconstructed prey biomass (%BM), the percentage of reconstructed biomass of prey represented by a particular prey category. The final reconstructed prey weight, which sums the calculated biomass of all ingested individuals, is an underestimation; broken, upper only, or unidentified beaks did not contribute to the total estimate of prey weight.

RESULTS

Pygmy Sperm Whale stranding events are rare in Tasmania, where this species comprises only 1.4% of total events and 0.3% of individuals stranded (DPIPWE unpubl. data). Between 1989 and 2009, a total of six Pygmy Sperm Whales (five events) have stranded along the Tasmanian coastline,

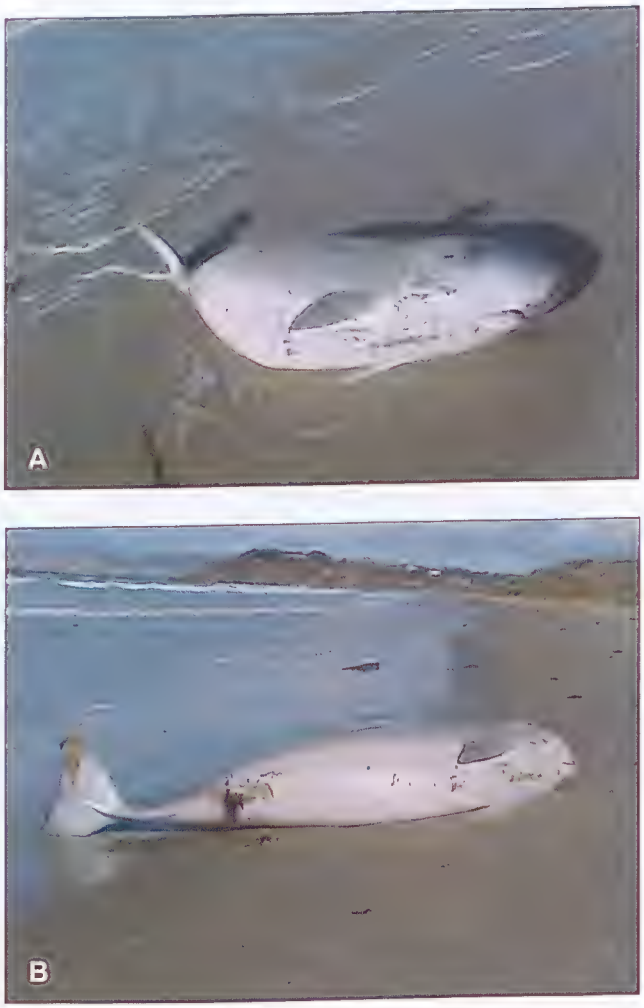

PLATE 1
A, B. Pygmy Sperm Whales that stranded on Carlton Beach, southeast Tasmania on 17 February 2003.

with an additional two historical museum records (table 1; fig. 1). All individuals were dead on discovery, except the individual found alive on Ocean Beach, which was apparently successfully returned to sea. Strandings have been primarily single adults, with two juveniles (male and female) recovered from Carlton Beach in 2003 (pl. 1). There are no records of calves stranding along the Tasmanian coast. No confirmed at-sea sightings of Pygmy Sperm Whales have been reported from Tasmanian waters.

Of the five Pygmy Sperm Whale carcasses recovered, detailed necropsies were performed on only the two individuals recovered from Carlton Beach, where cause of death was unknown. Large numbers of nematodes (species unknown) were present in the stomachs of both animals, and there were numerous squid sucker marks (5–10 mm) around the heads of both individuals. The stomach of the male contained prey items, whereas the stomach of the female contained only nematodes.

Neither fresh food remains nor bony fish or other contents were recovered from the male individual. The only available dietary information thus results from the analysis of accumulated beaks of cephalopods found throughout the stomach (i.e., forestomach, main stomach, connecting chamber and pyloric stomach). A total of 106 beaks (54 lower and 52 upper beaks) were recovered. The average LRL, mantle length (ML) and biomass (BM) for all squid species, and details of all regression equations describing

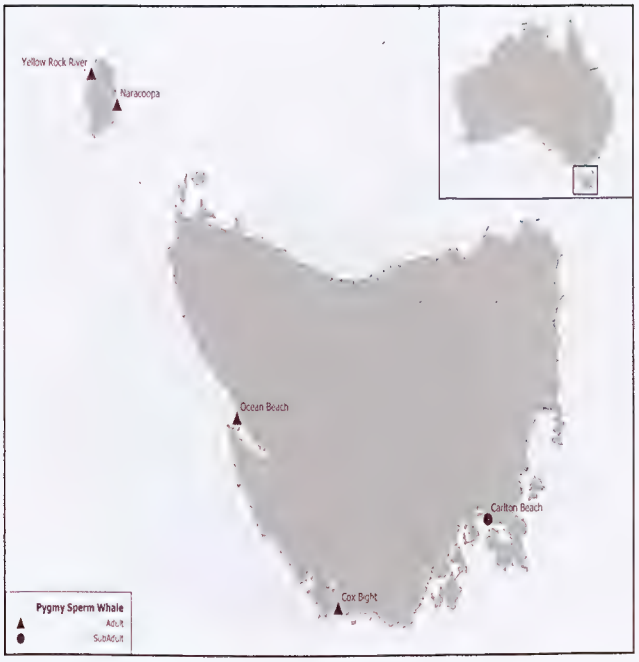

FIG. 1 — Location map of Tasmania showing stranding locations of Pygmy Sperm Whales; including Carlton Beach from where the analysed stomach sample originated.

the relationships of LRL versus ML and BM, calculated and compared in this study are summarised in appendix 1. These comparisons are important to determine the relative importance of prey items and determine size range (i.e., age class and subsequently life-stage) of prey consumed in order to better understand the foraging ecology of marine predators. The smallest (by BM) cephalopod recovered was a *Heteroteuthis* sp., estimated at 1.6 g (ML=16 mm). The largest squid recovered was an ommastrephid species with an estimated BM of 544 g (ML=279 mm).

The cephalopod composition of the dietary items consisted of at least 11 species from nine families. Based on the recovered prey, the reconstituted weight of prey remains recovered was equivalent to three kilograms. The most important family according to numerical abundance was Enoploteuthidae (*Enoploteuthis* sp.) 56%, followed by Histioteuthidae (*Histioteuthis atlantica* Hoyle, 1885 and *H. miranda* Berry, 1918) 19%, Cranchiidae (*Cranchia scabra* Leach, 1817 and *Teuthowenia pellucida* Chun, 1910) 9%, and Ommastrephidae sp. 6%. Chiroteuthidae (*Chiroteuthis veranyi* Férussac, 1835) 4% numerical abundance, was also a prey item of this whale. Low numbers of Brachioteuthidae (*Brachioteuthis linkovskyi* Lipinski, 2001), Nototeuthidae (*Nototeuthis dimegacotyle*: Nesis & Nikitina, 1986), Pyroteuthidae (*Pyroteuthis margaritifera* Ruppell, 1844), and Sepiolidae (*Heteroteuthis* sp.) were also recovered (table 2; fig. 2a).

Histioteuthidae comprised the most biomass consumed (30%), followed by Ommastrephidae (27%) and Enoploteuthidae (25%). These three cephalopod families comprised 82% of all cephalopod biomass consumed (fig. 2b).

Teuthowenia pellucida consisted entirely of juveniles, with mantle lengths ranging from 92–130 mm. *Histoteuthis atlantica*, *Enoploteuthis* sp. and *Ommastrephidae* sp. were all well represented by a mixture of juveniles and adults, with mantle lengths ranging from 19–135 mm, 14–109 mm and 138–279 mm, respectively. *Chiroteuthis veranyi* was the only prey that consisted primarily of adults, ranging in mantle lengths from 154–199 mm. One adult *Heteroteuthis* sp., with a mantle length of 16 mm was also consumed.

DISCUSSION

All cephalopod species recovered are commonly found in Tasmanian waters (Evans & Hindell 2004). An absence of neritic cephalopod species (such as Octopoda [octopuses], Sepiidae [cuttlefish] and *Sepioteuthis* sp.), compared to a high proportion of midwater oceanic cephalopod species (Enoploteuthidae, Histioteuthidae and Ommastrephidae), indicate that this Pygmy Sperm Whale had recently eaten, at least in part, in deeper offshore mesopelagic waters.

Histioteuthidae was the most important family consumed according to percent biomass, with several juvenile *Histioteuthis atlantica* (n=9) and one *H. miranda* of unknown age class identified. Histioteuthids have been

TABLE 1
Summary of all Pygmy Sperm Whale stranding and museum records from Tasmania

Date	Location	Decimal latitude and longitude	Sex	Age-class	Total length (cm)	Status on discovery
1870 (TMAG:A316[1])	Tasmania (no further locality information)	–	unknown	unknown	unknown	Dead
1935 (TMAG:A232)	Not Recorded	–	unknown	unknown	unknown	Dead
10-Sep-89	Cox Bight	–43.50, 146.21	male	adult	363	Dead
26-Apr-90	Naracoopa, King Island	–39.91, 144.13	unknown	adult	345	Dead
16-Jan-03	Ocean Beach, west coast	–42.14, 145.26	female	adult	340	Alive and released
17-Feb-03 (TMAG:A1757)	Carlton Beach, southeast coast	–42.87, 147.62	female	juvenile	215	Dead
17-Feb-03 (TMAG:A1758)	Carlton Beach, southeast coast	–42.87, 147.62	male	juvenile	200	Dead
7-Jun-04	Phoques Bay, King Island	–39.69, 143.88	unknown	adult	280	Dead

[1] TMAG number.

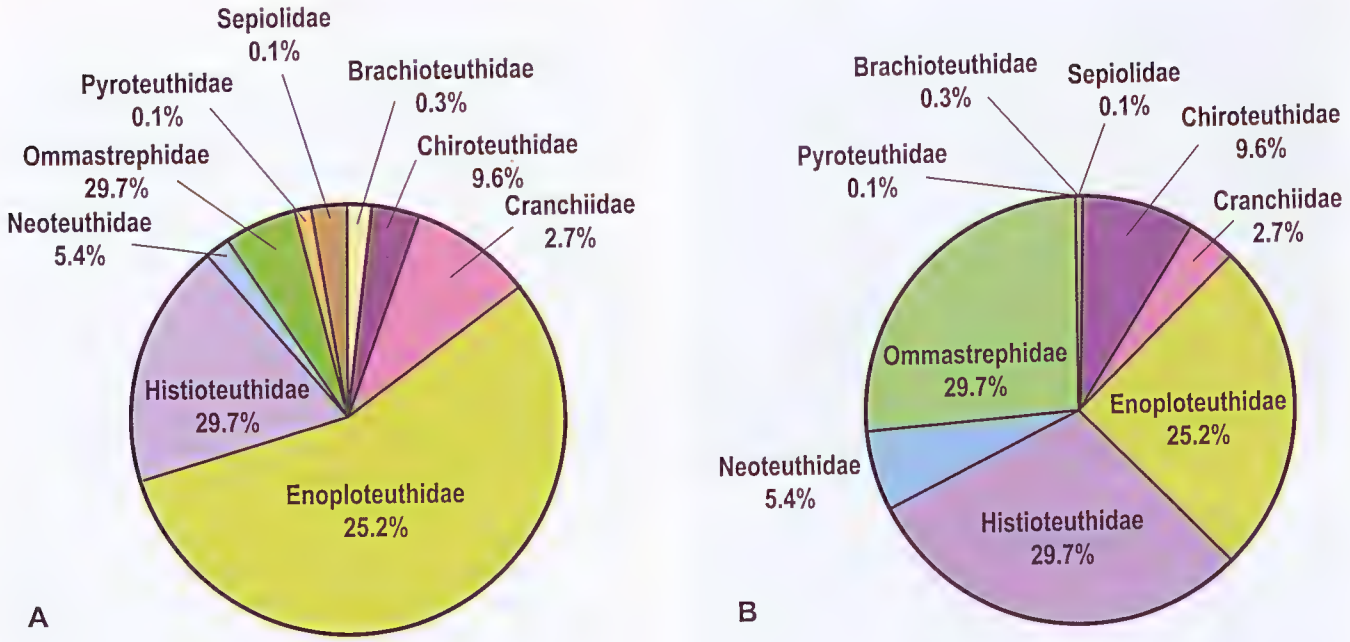

FIG. 2 — (A) % numerical abundance (%Num) and (B) % reconstructed prey mass (%BM) of cephalopod genera found in the diet of a juvenile Pygmy Sperm Whale stranded at Carlton Beach, southeast Tasmania on 17 February 2003.

TABLE 2
Mean lower rostral length or lower hood length (LRL/LHL), mantle length, and both mean and total wet weight biomass (BM), for all squid species examined

Family	Species	n[1]	LRL/LHL (mm)	Mantle length (mm)	BM (g)	Total BM (g)
Brachioteuthidae	*Brachioteuthis linkovskyi*	1	3.4	85.1	9.8	9.8
Chiroteuthidae	*Chiroteuthis veranyi*	2	6.7 ± 1.29 (5.8–7.7)	176.3 ± 31.48 (154.0–198.5)	141.4 ± 70.23 (91.8–191.1)	282.8
Cranchiidae	*Teuthowenia pellucida*	4	3.0 ± 0.68 (2.3–3.6)	112.6 ± 20.5 (91.6–130.2)	18.0 ± 7.60 (10.4–24.5)	72.0
Cranchiidae	*Cranchia scabra*	1	1.4	84.1	8.6	8.6
Enoploteuthidae	*Enoploteuthidae* sp.	30	3.5 ± 0.76 (1.0–4.3)	85.7 ± 21.5 (13.6–109.2)	26.5 ± 9.33 (0.87–42.2)	740.6
Histioteuthidae	*Histioteuthis atlantica*	9	2.3 ± 1.62 (1.1–5.7)	48.1 ± 41.6 (18.8–135.1)	63.2 ± 106.53 (6.1–311.4)	568.5
Histioteuthidae	*Histioteuthis miranda*	1	5	122.4	303.35	303.4
Neoteuthidae	*Nototeuthis dimegacotyle*	1	3.7	197.1	54.1	158.3
Ommastrephidae	*Ommastrephidae* (unknown sp.)	3	5.3 ± 1.70 (3.6–7.0)	208.9 ± 70.31 (138.4–279.0)	396.4 ± 208.03 (249.3–543.5)	792.8
Pyroteuthidae	*Pyroteuthis margaritifera*	1	1	32.3	2.7	2.7
Sepiolidae	*Heteroteuthis* sp.	1	1.16	15.6	1.6	1.6
Total		**54**				**2941**

[1] All values for which n >1 are expressed as mean ±SD (range).

listed as a dominant cephalopod prey in all other Pygmy Sperm Whale diet studies, except those from Taiwan (Wang *et al.* 2002), and comprised 73% of the mass consumed by Pygmy Sperm Whales recovered from New Zealand (Beatson 2007). *Histioteuthis atlantica* has a circumglobal distribution in southern waters and is regularly found in ocean basins, and over shelves and plateaux (Voss *et al.* 1998). Only *H. miranda* was found in Pygmy Sperm Whale samples from New Zealand, along with *H. macrohista* Voss, 1969, *Histioteuthis* sp. 2, (Beatson 2007), and a single beak later confirmed to be *H.* Type A5 by Horstkotte (2008).

Ommastrephidae was the next most important family consumed according to percent biomass. The unidentified ommastrephids were likely to be *Nototodarus gouldi*, although *Ommastrephes bartramii* Lesueur, 1821 and *Todarodes* sp. are other possible candidates. *Nototodarus gouldi* McCoy, 1888 is found throughout the year in Australian continental shelf and slope waters (up to 500 m) and also appears seasonally in shallow coastal waters, where they are targeted by commercial fisheries (Nottage *et al.* 2007). *Nototodarus gouldi* was also found in New Zealand Pygmy Sperm Whale diet samples (7.21% mass consumed, Beatson 2007).

Enoploteuthidae was the third most important family consumed according to percent biomass. The enoploteuthids in Australian waters are represented by an abundance of small mesopelagic species (Brandt 1983). It remains uncertain which species were recovered in this study; however, they are likely to be *Abraliopsis gilchristi* Robson, 1924 and *Enoploteuthis galaxias* Berry, 1918, which are associated with the temperate continental shelf waters of northern New Zealand and South Australia (Tsuchiya 2009). *Abraliopsis gilchristi* Robson, 1924 and *E. galaxias* Berry, 1918 are considered mesopelagic boundary species (the pelagic zone extending from 200 m down to around 800 m) (Young 1995).

Most cranchiid species occupy progressively deeper waters as they grow (ontogenetic descent), remaining in near-surface waters until reaching sizes of 50–100 mm ML (Young & Mangold 2008). *Teuthowenia pellucida* occurs only in the southern hemisphere and reaches a maximum size of approximately 200 mm ML (Young & Mangold 2008). Its systematics, biogeography and various aspects of its biology have been discussed in detail by Voss (1985). Numerous *T. pellucida* were also recovered from New Zealand Pygmy Sperm Whale samples (8% mass consumed, Beatson 2007).

One *Nototeuthis dimegacotyle* Nesis & Nikitina, 1986 was recovered. This recently described species was captured between the Southern Subtropical and the Antarctic Polar frontal zones in waters from 30–60 m and 0–500 m deep respectively (Nesis & Nikitina 1992). *Nototeuthis dimegacotyle* was not recorded from the New Zealand Pygmy Sperm Whale study (Beatson 2007), but has been previously recorded in the diet of Patagonian toothfish (*Dissostichus eleginoides*) at Crozet (5% by number) and Kerguelen (rare), Southern Ocean (Cherel *et al.* 2004).

Chiroteuthidae (juveniles occur near the sea surface, while adults live much deeper: Roper & Young 1975); Brachioteuthidae (deep-diving with the upper limits of daytime distribution probably at 600–700 m depending on the locality (Roper & Young 1975)); and Sepiolidae (shallow-living cephalopod family that occurs in the upper few hundred metres during both day and night (Roper &

TABLE 3
Cephalopod species composition in the diet of the juvenile male Pygmy Sperm Whale stranded at Carlton Beach, southeast Tasmania on 17 February 2003, ranked according to the % numerical abundance

Family and species	Total number	%Num[1]	BM[2]	%BM[3]
Enoploteuthidae (*Enoploteuthis* sp.)	**30**	**55.6**	**740.6**	**25.2**
Histioteuthide	**10**	**18.5**	**871.8**	**29.7**
Histioteuthis atlantica	*9*	*16.7*	*568.5*	*19.3*
Histioteuthis miranda	*1*	*1.9*	*303.4*	*10.3*
Cranchiidae	**5**	**9.3**	**80.6**	**2.7**
Cranchia scabra	*1*	*1.9*	*8.6*	*0.3*
Teuthowenia pellucida	*4*	*7.4*	*72.0*	*2.5*
Ommastrephidae (unknown sp.).	**3**	**5.6**	**792.8**	**27.0**
Chiroteuthidae (*Chiroteuthis veranyi*)	**2**	**3.7**	**282.8**	**9.6**
Neoteuthidae (*Nototeuthis dimegacotyle*)	**1**	**1.9**	**158.3**	**5.4**
Brachioteuthidae (*Brachioteuthis linkovskyi*)	**1**	**1.9**	**9.8**	**0.3**
Pyroteuthidae (*Pyroteuthis margaritifera*)	**1**	**1.9**	**2.7**	**0.1**
Sepiolidae (*Heteroteuthis* sp.)	**1**	**1.9**	**1.6**	**0.1**
Total lower beaks	**54**		**2941**	
Total upper beaks	**52**			

[1] %Num = proportion of numerical abundance
[2] BM (grams) = reconstructed prey biomass
[3] %BM = proportion of reconstructed prey biomass

Young 1975)), were the least important families identified in the Tasmanian Pygmy Sperm Whales' diet. Although chiroteuthids were significant components of the diet in the New Zealand study, *Brachioteuthis* and *Heteroteuthis* were also recorded in low numbers (Beatson 2007).

Our finding that the stomach of the Pygmy Sperm Whale from Carlton Beach contained primarily mesopelagic cephalopod species is broadly consistent with the New Zealand study (Beatson 2007), and other studies on Pygmy Sperm Whale diet from throughout their range, such as waters surrounding the Azores (Martins *et al.* 1985), Brazil (Secchi *et al.* 1994, Santos & Haimovici 2001, 2002), the Canary Islands (Hernandez-Garcia & Martin 1996, Fernandez *et al.* 2009), the Caribbean (Cardona-Maldonado & Mignucci-Giannoni 1999), South Africa (Ross 1979, Klages *et al.* 1989, Sekiguchi *et al.* 1992, Plön *et al.* 1999), the Atlantic coasts of the United States and Canada (Raun *et al.* 1970, Candela 1987, McAlpine *et al.* 1997, Santos *et al.* 2006), the Pacific coasts of the United States and Mexico (Scheffer and Slipp 1948, Eliason & Houck 1986, Vidal *et al.* 1987), the Hawaiian Archipelago (West *et al.* 2009), and Taiwan (Wang *et al.* 2002).

Acknowledging the limitations of diet studies (Bigg & Fawcett 1985, Jobling & Breiby 1986, Pierce & Boyle 1991, Gannon *et al.* 1997) and the problems and biases that act to favour the underestimation of the relative importance of fish and the overestimation of cephalopods (Gannon *et al.* 1997), it remains evident that cephalopods appear to be the major component of Pygmy Sperm Whale diet in southern Australian waters. More stomach samples, including some stomachs with undigested components are required for further studies. Although this study represents only a single individual, it provides an insight into a component of the foraging ecology of this little-known species, and a basis for comparison to both past and future studies in Australia and worldwide. Further Pygmy Sperm Whale diet studies from around Australia are required to determine additional target prey in Australian waters, and allow more comprehensive comparisons with worldwide studies.

Despite the seemingly high frequency of Pygmy Sperm Whale strandings in some Australian states, there remains very little published or unpublished information on diet, life history or comparative studies based on collected tissue samples (if collected at all). Inferring from the stranding record, Pygmy Sperm Whales are rarely encountered in the Tasmanian region, possibly in contrast to other areas of Australia (e.g., New South Wales) and New Zealand (where it is one of the most commonly stranded cetacean species) (Beatson 2007). Regional differences in species distribution should be considered in management initiatives.

Pelagic cephalopods are a major component of Pygmy Sperm Whale diet, and these are also affected by targeted fisheries (e.g., *N. gouldi*) and trawling activities around Australia (which are known to destroy the gelatinous egg masses of many pelagic cephalopod prey species (O'Shea *et al.* 2004, Beatson 2007). The importance of cephalopods in the diets of keystone predators (e.g., cetaceans, pinnipeds and seabirds) in the Tasmanian region, and Australia-wide, should be carefully considered in the sustainable management of the commercial cephalopod fishery.

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APPENDIX 1
Regression equations used for calculation of mantle length (ML) and reconstructed biomass (BM)

Family	Species	Author	LRL versus ML (n)	LRL versus BM (n)
Brachioteuthidae	*Brachioteuthis linkovskyi*	Clarke (1986)/Xavier & Cherel (2009)	ML = 16.31 ± 20.18(LRL) (n=11)	BM = 0.55 ± 1.41 ln(LRL) (n=11)
Chiroteuthidae	*Chiroteuthis veranyi*	Clarke (1980)/Xavier & Cherel (2009)	ML = 11.4 ± 24.46(LRL) (n=23)	BM = -0.241 ± 2.7 ln(LRL) (n=14)
Cranchiidae	*Cranchia scabra*	Clarke (1986)	ML = 17.8 ± 48.72(LRL) (n=45)	BM = 1.58 ± 1.85 ln(LRL) (n=40)
Cranchiidae	*Teuthowenia pellucida*	Rodhouse et al. (1990)/ Xavier & Cherel (2009)	ML = 22.27 ± 29.90 (LRL) (n=41)	BM = 0.71 ± 1.94 ln(LRL) (n=41)
Enoploteuthidae	*Enoploteuthis* sp.	Lu & Ickeringill 2002	ML = -13.04 ± 34.56 (LRL) (n=45)	BM = 0.32 ± 3.00 ln(LRL) (n=45)
Histioteuthidae	*Histioteuthis atlantica*	Lu & Ickeringill 2002/ Xavier & Cherel (2009)	ML = -10.42 ± 25.66(LRL) (n=21)	BM = 1.49 ± 2.45 ln(LRL) (n=19
Histioteuthidae	*Histioteuthis miranda*	Clarke (1986)/Xavier & Cherel (2009)	ML = -7.0 ± 25.82(LRL) (n=54)	BM = 1.783 ± 2.44 ln(LRL) (n=53)
Neoteuthidae	*Nototeuthis dimegacotyle* (based on *Alluroteuthis antarcticus* which is larger than *Neoteuthis dimegacotyle*)	Piatkowski *et al.* 2001	ML = -4.301 ± 34.99(LRL) (n=22)	BM = 1.229 ± 2.944 ln(LRL) (n=22)
Ommastrephidae	*Ommastrephidae* (unknown sp.)	Clarke (1986)/Xavier & Cherel (2009)	ML = -11.3 ± 41.36 LRL (n=83)	BM = 0.783 ± 2.83 ln(LRL) (n=83)
Pyrotheuthidae	*Pyroteuthis margaritifera*	Lu & Ickeringill 2002	ML = 5.26 ± 26.73(LRL) (n=25)	BM = 0.97 ± 2.70 ln(LRL) (n=25)
Sepiolidae	*Heteroteuthis* sp.	Lu & Ickeringill 2002	ML = -3.73 ± 16.66 LHL (n=25)	BM = 0.01 ± 3.12 ln(LHL) (n=25)

COLONIAL CORRESPONDENTS AND JOSEPH DALTON HOOKER

by Anita Hansen

(with two plates)

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Dr Joseph Dalton Hooker of Kew Gardens in London built his reputation as a botanist, to a large extent, on his publication of the floras of the southern ocean, namely his *The Botany of The Antarctic Voyage of HM Discovery Ships* Erebus *and* Terror, *in the Years 1839–1843*, a set of books that contains *Flora Antarctica, Flora Novae Zelandiae* and *Flora Tasmaniae*. Although Hooker had visited all of these places on the voyage and collected a substantial number of botanical specimens for his research, he alone could not have assembled the comprehensive herbarium needed for such a wide-ranging set of flora. To aid him in this endeavour, Hooker relied on an enthusiastic group of colonial correspondents and collectors. He regarded the specimens, and the information about them, sent by the colonial correspondents as belonging to the metropolitan centre at Kew. However, as these correspondents gained botanical knowledge, in particular William Archer, Ronald Campbell Gunn and William Colenso, they clamoured for recognition of their expertise, something Hooker was not always willing to bestow.
Key Words: William Archer, Joseph Dalton Hooker, natural history, botany, *Flora Tasmaniae*, Ronald Campbell Gunn, William Colenso.

INTRODUCTION

During the nineteenth century, Sir William Jackson Hooker (1785–1865) and his son Joseph Dalton Hooker (1817–1911) established a network of correspondents and collectors across the British Empire. There is a clear distinction between correspondents and collectors. As Stevens succinctly put it: "'Collectors' were just that; they collected." (Stevens 1997, p. 346), and they were usually paid to do so, while the correspondents were individuals whose interest in botany led them to send specimens and, most importantly, information about the specimens, to the Hookers without payment. Specimens of their local flora were sent to the Hookers, first to Glasgow University where William Hooker lectured in botany, and later to the Royal Botanic Gardens at Kew. These specimens would eventually make the herbarium at Kew the largest and most comprehensive in the world. Joseph Hooker established his career as one of the leading botanists of his era while having access to that vast herbarium. But was Hooker's knowledge gained purely by the use of the physical specimens?

Joseph Hooker also used critical botanical information provided by correspondents that related to the specimens — their characteristics, behaviour, habitat, location, and their environment — in the same manner that the herbarium specimens themselves were collected and used. That information was considered as much a possession of the metropolitan centre as the physical specimens themselves. This is demonstrated by the correspondence held at Kew Gardens between Joseph Hooker and a number of these colonial correspondents. The letters of the Tasmanians William Archer (1820–1874) and Ronald Campbell Gunn (1808–1881), and New Zealander William Colenso (1811–1899) both to and from the Hookers illustrate the reasons behind his need to use their information (Archer 1847–1874, Burns & Skemp 1961, Endersby 2001, 2008a). It was to these three colonial correspondents that Hooker dedicated two of the volumes of his Antarctic research: *Flora Tasmaniae* (Hooker 1860) to Archer and Gunn) and *Flora Novae Zelandiae* (to Colenso). Although Hooker also dedicated *Flora Novae Zelandiae* (Hooker 1853) to Andrew Sinclair (c. 1796–1861) and David Lyall (1817–1895) for their assistance, they are not included here as they were not long-term residents of the colonies.

SCIENCE IN THE VICTORIAN ERA

The eighteenth and nineteenth centuries were a period of great British scientific voyages and of rapid expansion of the British Empire. This coincided with an era that Holmes (2009) terms the "second scientific revolution", defined as dating between Captain James Cook's circumnavigation voyage in the *Endeavour*, begun in 1768, and that of Charles Darwin's voyage aboard the *Beagle*, begun in 1831. Cook (1728–1779) landed in New Zealand in 1769, and then sailed on to New Holland (later Australia), claiming the east coast for England in 1770.

While the early European discovery and exploration of Australia and New Zealand was carried out by the British navy, the fauna and flora specimens collected on those expeditions were often held by private individuals — for example, Sir Joseph Banks and Charles Darwin — wealthy men who joined the expeditions in a civilian capacity in search of new and exotic natural history specimens. In Britain during this period, the study of natural history was, on the whole, only able to be practised full-time by men of independent means. However, realising the economic potential in some of the new botanical discoveries, naval officers were assigned to collect specimens on many later British expeditions of exploration. The botanical samples from official government expeditions were usually sent to Kew Gardens, and remained the property of the Admiralty. As Stevens noted: "When the Botanic Gardens at Kew were established in 1841, it was with the express understanding by the government that they should be the botanical centre of the British Empire and coordinate its botanical activities" (Stevens 1997, p. 356). It was acknowledged that the naval officers "would have the sole right, apart from the captain, to produce an Admiralty supported publication of scientific observations" (McCalman 2009, p. 86). One such naval officer wanting to publish scientific observations from a

voyage was Joseph Dalton Hooker, who had been the assistant surgeon on the 1839–1843 James Ross Clarke Antarctic expedition.

JOSEPH HOOKER AND PHILOSOPHICAL BOTANY

Joseph Dalton Hooker was the second son of William Jackson Hooker, Regius Professor of Botany at Glasgow University, and later director of Kew Gardens. From an early age Hooker had developed a passion for natural history, and his father wrote to one of his Tasmanian collectors, Ronald Campbell Gunn, "... my second son [Joseph] him being already a very respectable Botanist, has begun Entomology" (Hooker 1822). In many of his following letters Sir William asked for insect specimens for Joseph, as well as botanical specimens for his own herbarium.

As he grew, Joseph Hooker sought to make his name as a botanist. He saw it almost as his right (Bellon 2001), and he soon realised that to accomplish his aim of botanical fame, he needed to accompany one of the great voyages of discovery, to reach some areas that were relatively unexplored where hopefully interesting new plants could be found. The young Joseph Hooker was advised to study medicine to enable him to join the James Clark Ross Antarctic expedition of 1839 as few positions as naturalist were available. He was employed as assistant surgeon on the expedition, not the position he had hoped for, but, as Hooker himself noted when writing to his father regarding his necessity to look for paid work to pursue this interest, "I am not independent, and must not be too proud: if I cannot be a naturalist with a fortune, I must not be too vain to take honorable compensation for my trouble" (Huxley 1918, p. 597). Upon his return to England in 1843, Hooker desperately needed to find paid employment, and in this he was aided by his father, now Director of Kew Gardens, who lobbied his many influential friends to arrange for Joseph to be employed there as Assistant Director. This and a government grant of £1000 towards the publication of his research from the Antarctic voyage would allow him to earn his living from botany as a "professional man of science" for some time to come (Endersby 2004).

Recently there has been a number of articles and books written on the topic of the terms "professional" or "philosophical" scientist as used in Victorian Britain in the mid-nineteenth century. Endersby (2008b) and Bellon (2006) write of Joseph Hooker and his struggle to create a respected, and respectable, position for himself in the world of botany. As Endersby wrote, "the meaning of the term 'gentleman' shifted during the nineteenth century, becoming deeply ambiguous as the claims of Britain's landed aristocracy to be the country's natural rulers were disputed by the rising middle classes. Nevertheless, it retained the connotation that disinterested service rather than paid employment was the proper way to pursue science. These ideals made life complicated for those, like Hooker, who wished to live by them, but still needed to earn a living" (Endersby 2008b, pp. 163–164).

An aspect of Hooker's "philosophical botany" and his role as a "working gentleman" that was to inform his pursuit of government patronage was his belief that, as Bellon (2001, p. 53) put it, "In pursuing research, the community would also serve the nation by promoting its health, education, defence, sustenance and honor. The nation in turn owed the scientific community for its ministration. This emphasis on mutual obligation between science and the nation made government both the most appealing and the most obvious reservoir of patronage among available sources".

Finally, and perhaps most critically, Hooker also had to institute and enforce a belief that the metropolitan centre, and only the metropolitan centre, had the necessary means and authority to describe and name new species of plants. He believed the correspondents at the colonial periphery could only be familiar with their own environment, and did not have the global view of the metropolitan botanist. That is, they could not have the expertise of the scientist who had access to a herbarium that contained specimens from across the world; "a naturalist's access to living plants, although a valuable card to hold, was not as valuable as access to unlimited herbarium specimens—*that* was the trump. The metropolitan botanist was able to control the colonial and the provincial" (Stevens 1997). However, as Endersby (2008a, p. 312) commented about his recent book: "One reason this book is called *Imperial Nature* is that Britain's political and economic empire provided crucial opportunities for men like Hooker to build careers; without the empire, men like Hooker, Huxley, Darwin, and Wallace would have had very limited access to the natural world beyond Britain's shores". Hooker could only hold the "trump card" because it had been dealt to him by the colonial correspondents. Access to the natural world would not have been enough to establish a career; there also had to be the right to sole use of that natural history.

THE NETWORK OF CORRESPONDENTS: TASMANIA AND NEW ZEALAND

Joseph Hooker visited Tasmania and New Zealand during his Antarctic expedition of 1839–1843. While on these visits he met and worked with two of his father's correspondents, Ronald Campbell Gunn in Tasmania, and William Colenso in New Zealand. Through their contact with Gunn, the Hookers would also later correspond with the Tasmanian-born William Archer. These three correspondents came from vastly diverse backgrounds: Gunn was a government official, Colenso a man of the cloth, and Archer a landed gentleman. They pursued their interest in botany for very different ideological reasons, and this, as well as their social standing, was reflected in the differing interaction Hooker had with each man (Hansen 2007).

Ronald Campbell Gunn was born in Cape Town, the son of an army lieutenant. He was educated in Aberdeen and went on to work as a clerk with the Royal Engineers in Antigua. In 1830 he joined his brother in Van Diemen's Land (later Tasmania) where he obtained a position as Assistant Superintendent of Convicts in Launceston. It was while working there he met and became friends with Robert Lawrence (1807–1833), a wealthy young landholder with a keen interest in botany, who was to spark Gunn's fascination with collecting (Burns & Skemp 1961). After Lawrence sent a letter of introduction, Gunn began writing to William Hooker in 1832 (Burns & Skemp 1961). Gunn met Joseph Hooker in 1840, when the *Erebus* and *Terror* of the Clark Ross Antarctic Expedition visited the colony. At the time Gunn was working as private secretary to Sir John Franklin, then Lieutenant Governor of Van Diemen's Land. Hooker later wrote of the time spent in Tasmania, "I can recall no happier weeks of my various wanderings

over the globe, than those spent with Mr. Gunn, collecting in the Tasmanian mountains and forests, or studying our plants in his library, with the works of our predecessors Labillardière and Brown" (Burns & Skemp 1961, p. viii). They continued to exchange letters for more than 20 years.

Gunn's interest in botany was associated with his desire to pursue the interests of a gentleman in the class-conscious Victorian era, and indeed, he stressed to Hooker in many of his letters that he did not wish any recompense for his specimens despite the great expense, in both time and money, he incurred in collecting them and forwarding them to England. He did, however, request that books on botany be sent for him to study, which the Hookers did happily, though not purely for altruistic reasons (Burns & Skemp 1961). They knew that the greater the botanical knowledge of the correspondents, the better the specimens sent. Gunn continued his interest in natural history for many years, becoming a Fellow of The Royal Society of Tasmania, and a Fellow of the Linnean Society of London in 1850, the first Tasmanian to do so. Gunn introduced fellow Royal Society member, William Archer, to the Hookers.

William Archer could pursue his passion for botany as a "disinterested gentleman". Archer was born in Launceston, northern Tasmania, the second son of a wealthy landowner. As a youth Archer travelled to England, where he studied architecture and engineering, returning to Tasmania in 1842 after an absence of six years. In 1848 Archer and his young family moved to Cheshunt, near Deloraine—a property given to him by his father (Archer 1847–74). This is the "Cheshunt" that features so prominently in Hooker's *Flora Tasmaniae*.

Archer joined The Royal Society of Tasmania in 1847, becoming a Fellow two years later. He was later elected a Fellow of the Linnean Society of London in 1857.

Archer not only sent botanical specimens to Kew, but also illustrations of some of the new plants he was encountering, especially the orchids (pl. 1).

Along with Ronald Campbell Gunn and William Archer in Tasmania, Hooker also corresponded with William Colenso in New Zealand. New Zealand was another British colony visited by the Clark Ross expedition in 1841 and Hooker and Colenso met at that time. Like Gunn in Tasmania, Hooker's early botanising with Colenso initiated what would become a life-long exchange of letters. Colenso was born in Penzance, Cornwall. At the age of 15 he was apprenticed to a local printer. After completing his apprenticeship Colenso was employed as a missionary-printer in New Zealand. He arrived at Paihia, Bay of Islands, in 1834. In 1843 Colenso went to Te Waimate to study for ordination as a deacon, before engaging in full-time missionary work (Foster 1966b).

Colenso had been interested in all branches of natural history from an early age, and the move to New Zealand with its exotic flora refuelled that interest. He made several botanical excursions, and published memoires of his discoveries on those journeys (Colenso 1854). He was elected a Fellow of the Royal Society in 1866, the first New Zealander to be so honoured (Foster 1966b).

THE RELATIONSHIP BETWEEN HOOKER AND THE COLONIAL CORRESPONDENTS

While the Hookers maintained a network of colonial correspondents that continued, in some cases, for several decades, those relationships were not always without tension. The correspondence between Archer, Gunn, Colenso and the Hookers showed a developing friendship that went far beyond that of a formal working relationship. However, as the correspondents gained more experience in collecting specimens and also acquired knowledge in botany, there developed in the letters exchanged a growing dissent concerning Hooker's disregard of their expertise. Endersby (2001, p. 343) highlighted this when he wrote: "Although Hooker was dependent upon people like Colenso [Gunn and Archer] for the specimens he needed to compile the books that made his name and reputation, he was not interested in their ideas", and while Hooker may not have been interested in their ideas, the correspondents over time had gained skills and knowledge that surely justified expressing those opinions. The colonial correspondents worked in a concentrated area over a period of years, examining every species and all their variations, before deciding what was and was not a new species".

In the mid-nineteenth century botanists were greatly divided on what constituted different species—divided between "lumpers" like Hooker, who looked at botany from a global perspective, interested in worldwide plant distribution, and "splitters" who worked on local environments and were inclined to examine these areas more closely—the metropolis (centre) and the province (periphery) (Endersby 2008a, Ison 2013). Those who had power, the men of the metropolis, could control what was published and who was recognised within these publications. As Endersby (2008a, p.19) wrote:

"One of Hooker's preferred strategies for abolishing the names that had been conferred by colonial or provincial naturalists was to compare the specimens the local naturalists had relied on with the much wider range he had available at Kew. Hooker argued that a global comparison demonstrated that the apparently distinct forms to which the local botanist had given names were in fact linked by intermediate forms from around the world. The varieties of the plant could then be lumped together as a single species, a process that, not surprisingly, many local collectors objected to, since it removed "their" names from the botanical record."

The colonial correspondents at the periphery argued that their local field experience enabled them to distinguish differences in species not able to be discerned in a dried herbarium specimen. Colenso wrote to Hooker, "I have also taken the 'universal' distinctive uses of the plant [*Phorium*] into consideration; and no New Zealander [that is, Maori] would (or could) ever use one sp. for the other" (Colenso 1854). However, Hooker refused to concede the usefulness of indigenous knowledge and he ignored Colenso's proposed names. From the colonial botanist's perspective, local knowledge was perhaps the best kind to have. Hooker matched them in craft skills and excelled them in his formal botanical education repeatedly denying the relevance or usefulness of such knowledge. Thus, he overruled it because acknowledging its validity would have tilted the trading terms too far in the colonists' favour (Endersby 2008b).

To counter the metropolitan reluctance to publish their work (yet they could see within works published by metropolitan botanists information they had sent used in the description of new species), the colonial correspondents created their own journals within the colonies where they could publish their findings. In 1842 Gunn wrote *Observations on the Flora of Geelong*, and began a seven-year

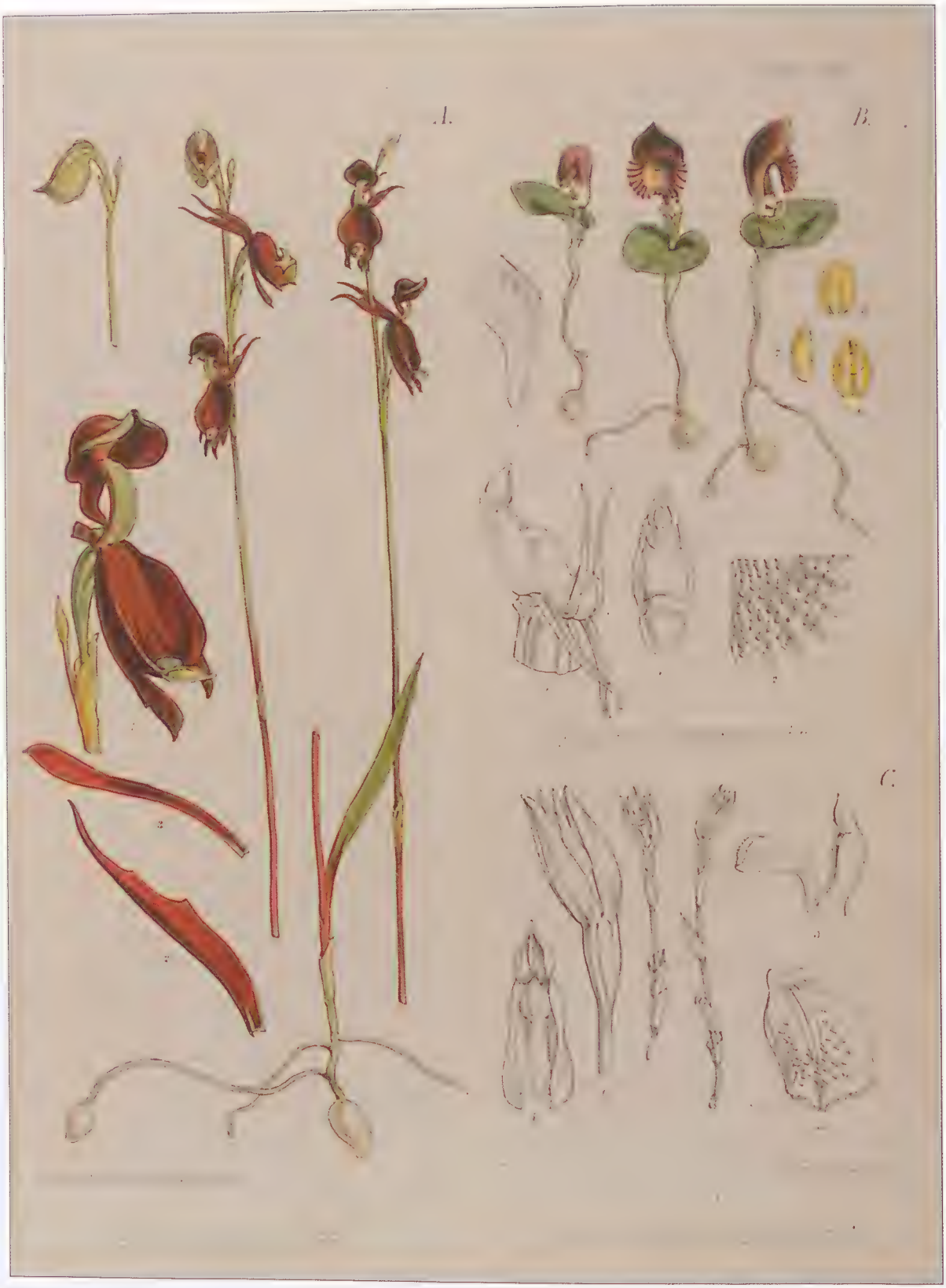

PLATE 1

Plate CXIII, Prasophyllum Archeri *(now* Corunastylis archeri *(Hook.f.) D.L.Jones & M.A.Clem.) Del. Archer, lith W Fitch. From Hooker, J.D. 1860:* Flora Tasmaniae, *Lovell Reeve, London, The Royal Society of Tasmania Library collection.*

editorship of the *Tasmanian Journal of Natural Science* in which many of his articles appeared (Burns & Skemp 2006). William Colenso countered the dismissal of his right to name species by publishing in colonial journals. Colenso contributed over 100 papers on various scientific subjects, many of great value, to scientific journals, principally to the *Transactions of the New Zealand Institute*. But as Endersby (2008a, p. 201) noted, "Whenever possible, Hooker would ignore any publication in a colonial journal, such as many of the names published by the Australian naturalist Ferdinand von Mueller ... Mueller's species concept was not the issue; his perceived 'lack of judgement', was a factor, but his real offense was refusing to be brought under Kew's control—publishing in colonial journals was just a symptom of his recalcitrance".

Hooker wanted to establish fewer journals, from fewer larger centres, preferably in Britain. Hooker and fellow botanist George Bentham (1800–1884) created what has been termed the "Kew Rule" which, in effect, saw the rejection of articles by colonial authors (Endersby 2008a).

On Hooker's recognition of the skills of the correspondents

The relationship between Hooker and his correspondents differed between individuals. When Hooker met Gunn and Colenso as a young man in the colonies, he met them as an officer of the Imperial Power and an expert in the field of botany. Although they were to become close friends, Gunn was a government official, used to obeying and deferring to authority, and it can be seen from his letters that Gunn was perhaps the least vocal in his concerns regarding acknowledgement of his expertise. He does, however, make some veiled comments about this matter when on 3 May 1845 he wrote to Joseph Hooker:

"Many thanks for calling the Cider tree *Eucalyptus Gunnii* ... I was most amused at your quotation from Breton's journal—which was in fact furnished by me—poor Breton never having seen the tree!! He ought in justice to have quoted me as his authority for the tree existing—as also for the manner of collecting the Sap, but he lives only on borrowed matter. Half of the source of his Journal was furnished by me over a bottle of wine at Penquite." (Burns & Skemp 2006).

Hooker had some more heated discussions with Colenso regarding the right to name specimens. Endersby (2001, p. 343) quoted Joseph Hooker when he wrote, "From having no Herbarium you have described as new, some of the best known Ferns in the world".

Hooker's relationship with William Archer appears to have been very different. Archer was a disinterested gentleman in the true sense. He was also a native-born Tasmanian. It is possible the combination of these two factors was important in making the relationship so different. Archer saw himself as a botanist, not merely a collector. Indeed, he is recognised as the first Australian-born botanist and botanical illustrator (Hewson 1999). He had had training as a professional in England, as an architect and engineer (Hansen 2007), and he certainly was a social equal (if not more) to Hooker. Archer was the youngest of the correspondents and also the last of the three to join the network. By that time Tasmania was beginning to gain a degree of independence from its British rulers. The year 1855 saw the first freely elected Legislative Council in Tasmania—Archer was one of these men. Archer's independent wealth, his belief in himself as a botanist, and his having been born in the colonies, allowed him to interact with Joseph Hooker in a completely different manner to correspondents like Gunn and Colenso. It seems Hooker also related to him in a different manner. Of all the correspondents, Archer was the only one to extensively illustrate his work. Of the three colonial protagonists he was the only one to travel to England to work with Hooker.

Archer worked closely with Hooker on *Flora Tasmaniae* over a period of more than two years, 1857–1859, particularly on the section on orchids. His skill as a botanist and botanical illustrator can be seen in his drawing of *Corybas diemenica* Lindl.— identified as *Corysanthes fimbriatus* Br. by Archer and Hooker in *Flora Tasmaniae* (Hooker 1860). In comparing Archer's originals and his notes concerning them, he clearly identified *Corysanthes diemenica* Lindl. as a distinct species. While in this case, Hooker overrode his suggestion, the orchidologist John Lindley (1799–1864) also suspected there to be at least two species (Hooker 1860). In his description of this orchid Hooker wrote:

"Common in various parts of the Island. Lindley distinguished this [Archer's illustration?] doubtfully as a different species from *Corysanthes fimbriata*, from its having larger flowers and less fimbriated margins to the labellum; but I find both the flowers and leaves to be extremely variable in absolute and relative size" (Hooker 1860, p. 16). Hooker lumped all three known *Corysanthes* species together as *Corysanthes fimbriata* R.Br in *Flora Tasmaniae* (Hansen 2007) (pl. 2).

However, it can be seen by the many references to Archer throughout the book, that Hooker did not always override his suggestions and his contribution was significant. Indeed, Hooker wrote in the *Introductory Essay* regarding Archer's contribution, "It remains only to mention my friend William Archer, Esq, FLS of Cheshunt, who, after a residence of upwards of ten years in Tasmania, during which he sedulously investigated the botany of the district surrounding his property, returned to England in 1857, with an excellent herbarium, copious notes, analyses, and drawings, and a fund of accurate information on the vegetation of his native land, which have been unreservedly placed at my disposal" (Hooker 1860).

It is interesting to note here that Hooker acknowledges the excellence of Archer's herbarium after being so disparaging of Colenso's colonial herbarium. Hooker then went on to say: "I am indeed very largely indebted to this gentleman, not only for the many plants described, and much of the information that I have embodied in this work, but for the active interest he has shown during its whole progress, and for the liberal contribution of the thirty additional plates" (Hooker 1860).

Despite Hooker's assertion that it was only access to a global herbarium that allowed the metropolitan botanist to have the knowledge necessary to describe new species, he acknowledged that Archer's familiarity with the living plants was beneficial. He wrote in *Flora Tasmaniae*, "On the other hand I have derived the greatest assistance from Mr Archer's drawings, notes, and specimens, as well as from his intimate acquaintance with the living plants ... and I can only add, that for his having afforded me the benefit of his accurate knowledge of the species, I should in several cases have failed to discriminate them aright, and in other cases, where I had properly discriminated, to have selected their most important diagnostic characters."

PLATE 2
Plate CVII, Corysanthes fimbriata. *Del Archer, lith W Fitch. From Hooker, J.D. 1860:* Flora Tasmaniae, *Lovell Reeve, London, The Royal Society of Tasmania Library collection.*

(Hooker 1860). Indeed, Hooker deferred to Archer's expertise on a number of occasions. During April and May 1857, Archer wrote in his diary, "Having received a letter from Dr Hooker respecting the number of species of *Thelymitra*, I commenced today a careful examination of my specimens, in order to assist him in determining the question ...Today I began to make my deductions from my observations, coming to the conclusion that there are 4 species, instead of 2, as Dr Hooker thinks ... I went to Kew to examine the Tasmanian Orchids with Dr Hooker. Dr H and I decided upon reducing all the species of *Thelymitra* to 3 & a possible 4th *T. nuda, ixioides, & augustifolia*, Br Prod." (Archer 1847–74).

Hooker's close collaboration with Archer on *Flora Tasmaniae* grew to the extent that he wrote "our" and "we" when describing their work. "I am indebted to Mr Archer for discriminating my specimens of this species, which were intermixed with *T. nuda* ... Brown's specimens in the British Museum are very small and slender, though not more so than many of ours, and we rely on the description of the lobes of the column for the identification of our plant with his" (Hooker 1860).

Archer's original illustrations of orchids and fungi were used as the source for a number of plates in *Flora Tasmaniae*. He was displeased with the inclusion of Kew Gardens' illustrator Walter Hood Fitch's (1817–1892) name on the plates. On 24 August 1857 Archer wrote to Hooker: "Mr Fitch is lithographing the drawings of orchids, and adds his name to mine as delineating them, somewhat unfairly I think, for at the most he only adds a flower or two, and an unnecessary drawing of a dissection, excepting in a very few cases" (Archer 1847–74). As a result Archer decided to donate a number of his original illustrations to the Linnean Society of London. The folio of 36 drawings featuring some of Archer's original illustrations used for *Flora Tasmaniae* held at the Linnean Society justifies Archer's anger at the inclusion of Fitch's name. In most cases there is very little change in Archer's drawing and that featured in *Flora Tasmaniae*. A further 33 orchid drawings, many also used as source material for *Flora Tasmaniae*, are held by the Tasmanian Museum and Art Gallery.

After his return to Tasmania from England in 1860, Archer was elected Secretary of The Royal Society of Tasmania, an office he held for two years. Archer and Hooker continued work on the *Supplement* to *Flora Tasmaniae* after Archer returned to Tasmania.

William Archer and Hooker maintained their correspondence until Archer's death in 1874.

The Colonial Correspondents and Patronage

Joseph Hooker's relationship with his colonial correspondents was one full of contradiction. He relied on their generosity of spirit in sending him specimens free of charge, while at times, he saw them almost as his employees. In 1847 he wrote to James Clark Ross, "Gunn and Colenso are still employed in making collections in all parts of these islands and are paid by my father and self for doing so, from our private pockets" (Huxley 1918, p.21). While the correspondents may have been sent supplies and books on botany, they were not paid for their specimens.

Not only were the correspondents not financially supported by Hooker, but in time they were to be in the position of financially supporting him. As they gained increasing expertise within their botanical pursuits, they were also gaining some independent wealth and status. Gunn had amassed property of his own and was no longer in government service. Colenso had resigned from the ministry and, like Gunn and Archer who were politicians, was a member of the New Zealand government. Archer, of course, had always been independently wealthy. Gunn and Archer were instrumental in securing the Tasmanian government's grant of £350 towards the cost of publishing *Flora Tasmaniae*, and indeed, Archer personally provided a further £100 towards the cost of publishing *Flora Tasmaniae*. After visiting William Archer in Tasmania, William Harvey, the noted Irish botanist, wrote in a letter to Hooker: "I like him *very much*—& I need not tell you that he is a *warm friend & admirer* of yours. You have had substantial proof thereof already—the Tasmanian grant to your flora having been altogether his device, management & doing" (Ducker 1988, pp. 195–196). Archer wrote to Hooker of the grant and of his own financial contribution in a letter dated 26 July 1854: "I was very much gratified at receiving your welcome reply to my communication respecting the grant of our Council to you...therefore I authorize you (& enclose a draft) to apply to my agent in London...for £100, to meet any additional expenses that you may incur on their [the orchid drawings] account." (Archer 1854).

CONCLUDING REMARKS

Dr Joseph Dalton Hooker is regarded as one of the pre-eminent botanists of the mid-to-late nineteenth century, instrumental in establishing botany as a profession. He was one of the first researchers into global distribution patterns in plants. He was able to accomplish this only with the aid of the almost limitless herbarium specimens at Kew Gardens; many of these specimens supplied by a network of collectors and correspondents in the far-flung colonies of the British Empire. Over time, a number of these correspondents gained significant botanical expertise enabling them to send, not only specimens, but also critical scientific information regarding these specimens, to Hooker. Only by using the additional information supplied by these correspondents was Hooker able to publish as extensively as he did. When the correspondents began to publish their own findings in colonial journals, Hooker countered this by establishing the Kew Rule, thereby denying them the right to name the species they were discovering.

One colonial correspondent, the Tasmanian-born William Archer, overcame the metropolitan botanists' prejudice against local knowledge by sailing to England to collaborate with Joseph Hooker on *Flora Tasmaniae*.

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THE EFFECT OF RECENT FIRE HISTORY ON THE ABUNDANCE AND VIABILITY OF LARGE SEEDS IN THE SOIL OF SCLEROPHYLL FOREST IN TASMANIA, AUSTRALIA

by Nicole Bezemer, J.B. Kirkpatrick and J.A. Wood

(with two text-figures, two plates, eight tables and one appendix)

Bezemer, N., Kirkpatrick, J.B. & Wood, J.A. 2013 (17:xii): The effect of recent fire history on the abundance and viability of large seeds in the soil of sclerophyll forest in Tasmania, Australia. *Papers and Proceedings of the Royal Society of Tasmania* 147: 41–50. ISSN 0080-4703. School of Geography and Environmental Studies, University of Tasmania, Private Bag 78, Hobart, Tasmania 7001, Australia (NB*, JBK); Royal Tasmanian Botanical Gardens, Queens Domain, Hobart, Tasmania 7000, Australia (JAW). *Author for correspondence. Email address: nbezemer@gmail.com

There are few data on the effects of recent fire history on the composition of soil seed banks in sclerophyll forest communities. We predicted that the abundance and viability of soil-stored seeds would vary with fire history. Soils were sampled from areas with six different fire histories on Mt Nelson, Tasmania, Australia. Large seeds were extracted by hand separation and tested for viability. Responses to at least one of the two strongly-correlated components of fire history were detected in several taxa and for native and exotic seed. Native seeds, exotic seeds, *Astroloma humifusum* seed and *Exocarpos cupressiformis* seed were all more abundant in the soils of areas with one or less fires in the last 60 years than in the soils of areas burnt five times over the last 60 years. The viability of *A. humifusum* seeds decreased with fire frequency. These results support the hypothesis that frequent and recent fire can deplete the soil seed bank, and reduce soil seed viability, at least for some large-seeded species and species groups.

Key Words: eucalypt forest, fire frequency, fire history, seed abundance, seed viability, soil seed bank, time-since-fire, *Astroloma humifusum*, *Exocarpos cupressiformis*.

INTRODUCTION

The long-term storage of seed in the soil (geospory) is an important life history strategy in plants (Fenner 1985, Bell 2001, Merritt & Rokich 2006). Soil seed banks provide a genetic reservoir, from which dormant seeds germinate simultaneously or intermittently once stimulated by environmental or disturbance cues (Merritt & Rokich 2006). Seed banks are in a constant state of flux, with predation, decay and senescence, movement of seeds within the soil and germination acting to remove the seeds that are periodically deposited (Harper 1977).

Fire seasonality and intensity have been shown to affect the emergence and survival of several scleromorphic shrub species (Knox & Clarke 2006). Responses to fire can be modified by other factors. For example, soil moisture, depth of seed placement in the soil, fire intensity and duration affect the germination of *Dodonea viscosa* (L.) Jacq. (Hodgkinson & Oxley 1990).

Fire may also alter seed bank composition by altering above-ground species composition. In dry sclerophyll forest near Sydney approximately 60% of floristic variation may be attributed to fire frequency (Morrison *et al.* 1995). Frequent fires may shift sclerophyllous communities towards resprouter dominance (Meney *et al.* 1994, Bell 2001), thus altering seed deposition and, consequently, the composition of the seed bank.

Seeds in the soil that do not germinate after the passage of fire are an important component of the residual seed bank (Auld & Denham 2006). Fire may prevent seed bank replenishment, thus depleting the residual store. In several genera of Ericaceae and Restionaceae, there was less viable seed in recently burnt sites than recently unburnt sites, with the total numbers of seeds in the soil varying from 9000 seeds/m^2 in unburnt sites to around 1500 seeds/m^2 in burnt sites (Meney *et al.* 1994). In heath communities, fire can deplete the seedbank by half (Pierce & Cowling 1991). In the jarrah (*Eucalyptus marginata* Sm.) forest of southwestern Australia, the germinable soil seedbank was greater three years after fire than in soils from sites burned one and 13–22 years ago (Koch *et al.* 2009). This previous work suggests that fire history has a strong influence on the persistent soil seed store.

Germination after fire does not fully explain depletion of the seedbank, even in communities adapted to fire. In *Acacia suaveolens* (Sm.) Willd., maximum post-fire seed rain coincides with the maturation of post-fire germinants, at approximately two to three years (Auld 1986). Soil seed stores peak 10 years after a fire, after which stores decline in abundance and viability with loss of adult fecundity and decay. Soil seed stores of other species, such as *Grevillea barklyana* F. Meull. ex Benth., peak 16 years after fire (Vaughton 1998). Therefore, the magnitude of the soil seed store will be influenced by primary juvenile periods and patterns of post-fire fecundity, both of which can potentially be affected by fire regime.

Much of the above work was based on germination trials, which may not provide a complete representation of the soil seed bank, although being highly efficient in revealing the presence and abundance of most species. *Exocarpos cupressiformis* Labill. and *Astroloma humifusum* (Cav.) R.Br., for example, are conspicuous elements of dry sclerophyll communities that are rarely recorded in germination trials. For example, Penman *et al.* (2008) did not record their presence in the seed bank, as both species, although present in the vegetation, failed to respond to treatments. The cues used to stimulate the germination of seeds in *in situ* trials may be different to the ones that break the dormancy of particular species (Ooi *et al.* 2007).

The seed banks of scleromorphic communities are poorly known in Tasmania. Gilfedder & Kirkpatrick (1993) compiled a list of species observed in semi-natural

paddocks in the Tasmanian Midlands, and recorded those they germinated from the soil seed bank. Wilkinson & Jennings (1994) tested the regeneration capacity of *Acacia melanoxylon* R.Br. after fire in northwestern Tasmanian wet sclerophyll forests, and found that high intensity burning destroyed 67% of the viable seed in the uppermost part of the soil profile, and stimulated the germination of most of the remainder.

Although fire or fire-related cues are essential to break the dormancy of many species, fire also kills seeds in the soil, and temporarily prevents replenishment of the seed bank by killing adult and juvenile plants. We therefore test the hypothesis that the soil seed bank of geosporous species in dry sclerophyll forest is affected by variation in fire history. Our results are confined to large-seeded species to enable us to collect a number of samples sufficient to compare several fire histories. We use physical extraction and testing for viability, rather than germination trials, to ensure confidence in the completeness of the data for our subset of species.

METHODS

Study area

The study area is located on Mt Nelson, Hobart, Tasmania (147°19'E, 42°54'S) in the property of the University of Tasmania (fig. 1). The area includes a north–south gully occupied by *Eucalyptus globulus* Labill. wet forest with an understorey dominated by tall shrubs and small trees, such as *Beyeria viscosa* (Labill.) Miq., *Pomaderris apetala* Labill., *Bedfordia salicina* (Labill.) DC., *Exocarpos cupressiformis* and *Coprosma quadrifida* (Labill.) B.L.Rob., with occasional emergent *Acacia melanoxylon*. To the east of the gully is a large tract of *Allocasuarina verticillata* (Lam.) L.A.S.Johnson dry forest, which also occurs in two smaller patches in the western part of the reserve (fig. 1). Here, the understorey ranges from sparse to shrubby, with common species including *Bursaria spinosa* Cav., *Dodonea viscosa*, *Astroloma humifusum*, and *Lepidosperma laterale* R.Br. To the west of the gully is *Eucalyptus pulchella* Desf./ *E. viminalis* Labill. dry forest, which extends in a wide tract along much of the western border. *Bursaria spinosa* and *D. viscosa*, as well as native grasses, ericaceous shrubs and sedges, are typical components of the understorey. The southern and highest part of the reserve is comprised mostly of *E. pulchella*/ *E. globulus*/ *E. viminalis*/ *E. ovata* Labill. dry forest. The understory is diverse, including most species already listed and additional species, notably *Epacris impressa* Labill., *Olearia ericoides* (Steetz) N.A.Wakef., *Ozothamnus ferrugineus* (Labill.) Sweet, *Lissanthe strigosa* (Sm.) R.Br., *Goodenia ovata* Sm. and *Pultenaea juniperina* Labill. Native grasses are prominent in the understorey. Small tracts of degraded *E. obliqua* L'Hér. dry forest and *E. ovata* dry forest occur along the southwestern perimeter (fig. 1).

Field data collection

Across the University Reserve, six different fire histories were mapped from aerial photographs or satellite images dated 1946, 1957, 1967, 1975, 1980, 1984, 1989, 2001, 2004, 2008 and 2012 (table 1, fig. 2). An equal number of sites (10 per fire history; 60 in total) were selected from each fire history. Sites were chosen within five metres of a mature *Acacia* tree to remove the current occurrence of the genus as a factor influencing seed distribution. For each site, vegetation type was recorded and plant species listed. Soil samples were collected from the uppermost 5 cm of soil using a metal ring with a diameter of 8 cm. The soil sample for each site was made up of nine sub-samples, with a total dry weight of c. 900 g/sample.

Laboratory analyses

The soil samples were dried overnight and large seeds separated out by breaking up and passing the soil through a 1.7 mm sieve. As sifting did not remove all the soil, seeds were then separated by hand. To avoid measurement bias, each sample was identified by a number from 1 to 60, instead of the area from which it was collected.

Seeds were identified by JAW using the seed collections held at the Royal Tasmanian Botanical Gardens. Some seeds were identifiable only to genus level. The seeds of different taxa were described and photographed (appendix 1). The viability of each seed was determined using the cut test of Terry *et al.* (2003). Seeds in which the embryo appeared intact and healthy, and the endosperm clean and firm, were classed as viable.

Statistical analyses

Minitab 16 (Minitab Inc. 2010) was used in all analyses. In vegetation in which structure and dominance can be strongly influenced by fire regime, floristic classifications can better reflect underlying environmental gradients, and can be a better integral of past vegetation conditions, than dominance/structural groups. For these reasons, floristic groups were generated from the above ground vegetation presence/absence data for each site. An agglomerative strategy using Euclidean distance and Ward's method was adopted. Five groups were selected as there was a marked difference in average distance values between five and four groups.

For taxa with sufficient seed-bank data, one-way ANOVA was used to determine whether the abundance of seed varied with the presence or absence of a species in the above-ground vegetation at each site. Areas with high fire frequency strongly tended to be those with a short time since the last fire. This strong inverse relationship between the two attributes of fire regime required two sets of models in which number of fires was the fixed variable in one set and time since fire was the fixed variable in the other set.

TABLE 1
Known fire histories of the University Reserve

Fire history	No. of fires	Time-since-fire (years)
No fire in last 50 years	0	c. 60
Last fire 1967	1	45
1967, 1995	2	17
1967[1], 1995	3	17
1967, 1995, 1998	3	14
1967[1], 1995, 1998, 2006	5	6

[1] At least one low intensity fire between 1967 and 1995.

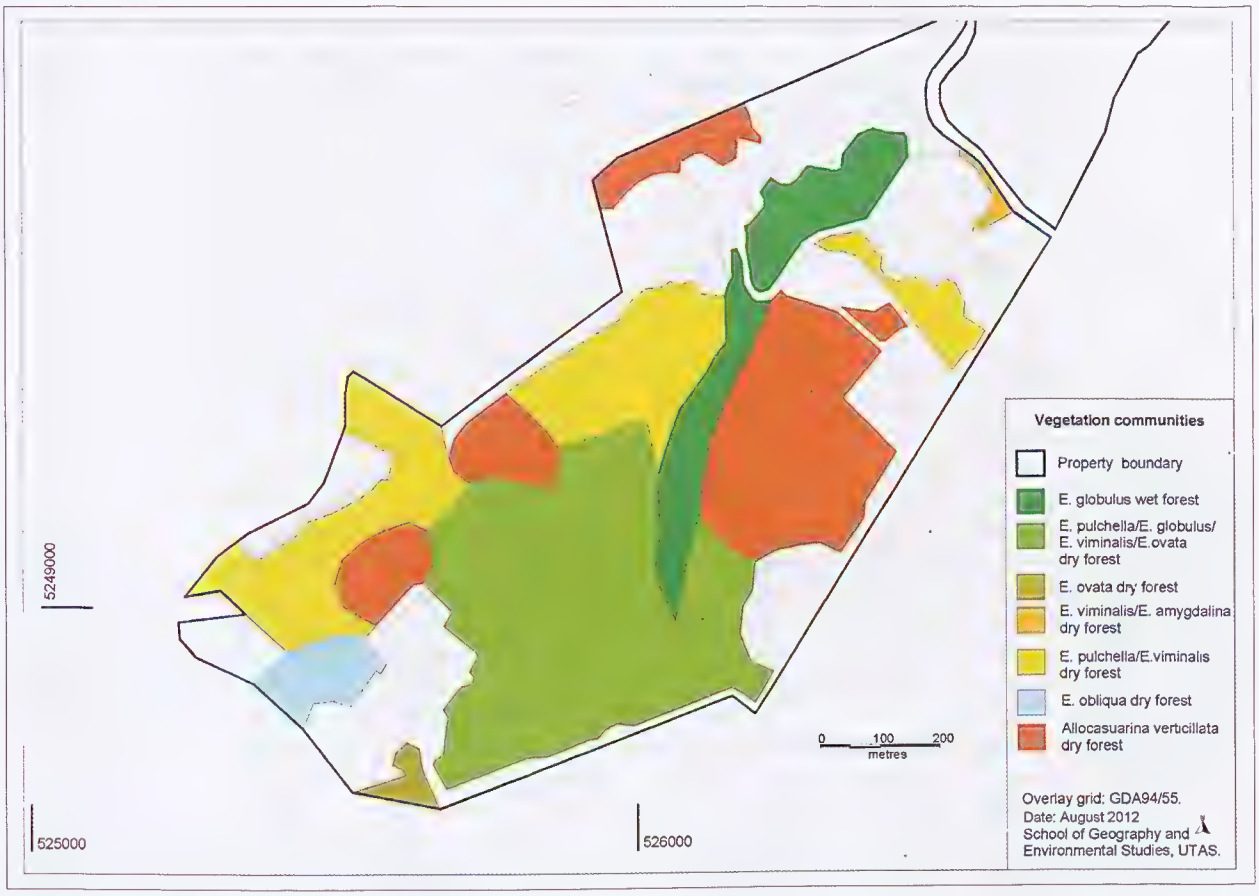

FIG. 1 — Vegetation types of the study area. Vegetation boundaries are based on the Biodiversity Management Plan (2012 draft) for the University Reserve. Base data from theLIST (www.thelist.tas.gov.au). © State of Tasmania

FIG. 2 — The recent fire history of the University Reserve, Tasmania (147°19'E, 42°54'S) and sample collection sites. Fire history boundaries are based on the Biodiversity Management Plan (2012 draft) for the University Reserve. Base data from theLIST (www.thelist.tas.gov.au). © State of Tasmania

In both sets, vegetation type (five categories, as described above) and floristic group were included as random factors. The response variables were soil seed abundance for *Acacia*, *Astroloma humifusum*, *Beyeria viscosa*, *Dodonea viscosa*, *Exocarpos cupressiformis*, *Lepidosperma laterale*, *Rubus fruticosus* (L.) sp. agg., total native seed and total exotic seed. Two sets of general linear models with the same predictors were constructed for seed viability for those of the above species and species aggregates for which there were sufficient data.

RESULTS

Fourteen types of seed larger than 1.7 mm were found in the soil samples, 10 of which were identifiable to species or genus (appendix 1). Several of these taxa were too infrequent in the sample to analyse. The abundance of *Beyeria viscosa* seed in the soil was strongly related to its occurrence in the vegetation, whereas *Astroloma humifusum*, *Dodonea viscosa*, *Exocarpos cupressiformis*, *Lepidosperma laterale*, and *Rubus fruticosus* seed did not differ in abundance between sites in which they occurred and those in which they did not occur (table 2).

The number of fires between 1960 and 2012 was strongly related to the number of native and exotic seeds in the soil (table 3), seed number decreasing with the number of fires (table 4). *A. humifusum*, *E. cupressiformis* and *R. fruticosus* seed numbers also declined as the number of fires increased (tables 4 and 5). *E. cupressiformis*, as well as native and exotic seeds considered as a group, also had strong responses to time-since-fire (table 3). *D. viscosa*, *B. viscosa*, *Acacia* and *L. laterale* did not have a significant response to either number of fires or time-since-fire. While vegetation type was not significant in any of the models, floristic group affected the abundance of native, exotic, *D. viscosa* and *R. fruticosus* seeds in at least one of the analyses.

The seed viability of *A. humifusum* was related to the number of fires and time-since-fire (table 6). Native and *E. cupressiformis* seed viability was related to floristic group (table 5). Viability of native and *A. humifusum* seed was highest (46.8 and 53.3% respectively) in the area not burnt in the last 50 years and lowest (13.9 and 6.2%) in the area burnt in 1967+, 1995 and 1998 (tables 7 and 8).

DISCUSSION

The 12 identified types of seed recovered from the soils of the study area (appendix 1) represented a small proportion of the 150 species of vascular plants recorded from the study area by one of us (JBK) and the 135 vascular plant species identified through germination trials in the soil seed bank of a grassy forest in southeastern Australia (Lunt 1997). Many species known to occur in the study area were not detected in the seed bank, despite having seeds > 1.7 mm in diameter. This result may indicate rarity of large seeds in the soil, or an insufficient sample size. Nevertheless, our procedures gave us confidence that our results reflected the reality of soil seed content for the subset of species with large seeds. We were able to count seeds of species, such as *Exocarpos cupressiformis*, that do not respond to normal germination trial procedures.

The distribution of the seed of *Astroloma humifusum*, *Dodonea viscosa*, *E. cupressiformis*, *L. laterale* and *Rubus fruticosus* was independent of the presence of the species in the contemporary vegetation (table 2), suggesting, in combination with the tendency of some of them to accumulate soil seed with time elapsed since fire, that these species have a persistent soil seed store. Among the above species, *A. humifusum*, *E. cupressiformis* and *R. fruticosus* have fleshy fruits or arils, so may be widespread in the soil seed store because of bird dispersal. The positive relationship between *Beyeria viscosa* soil seed and its contemporary presence in the vegetation reflects its restricted distribution in the study area and its lack of attraction for birds and mammals. The species was only found in wet eucalypt forest that had not been burned since 1967, where it had a substantial seed store, with more than 60% viability. Many of the viable seeds had heavily weathered coats, suggesting that this species has a persistent seed store.

Previous Tasmanian soil seed bank studies (Gilfedder & Kirkpatrick 1993, Wilkinson & Jennings 1994) did not record *E. cupressiformis*, *A. humifusum* or *L. laterale*, the seeds of which were common in our samples. In contrast, *Acacia* species have been observed to have a soil seed store (Wilkinson & Jennings 1994), as in our study area.

There was a strong relationship between the least burned areas and the more mesic parts of the study area, although all fire histories had at least some wet and some dry forest. To the extent that was possible given this partial coincidence, we removed the effects of vegetation by making vegetation variables random within our models (tables 3 and 6). This modelling procedure accounts for the lack of statistical effect from the fire variables for seed numbers for several of our taxa and groups, despite the raw data (tables 4, 5, 7, 8) suggesting stronger patterns. For example, the low mean abundance of *A. humifusum* seed in the areas with the longest time elapsed since fire (table 5) may be largely an artefact of its inability to survive in wet eucalypt forest.

The lack of influence in the models of the vegetation types, while floristic groups were shown to have some influence, suggests that longer term influences, such as environment and the integral of fire history, have more effect on the soil seed store than the structural-dominance vegetation types present at a particular time.

After accounting for the vegetation effect, we were able to demonstrate some strong associations between frequent and recent fire and low numbers and low viability of soil-stored seed. Native seeds in the soil, predominantly comprised of *A. humifusum* and *E. cupressiformis*, declined with increasing number of fires and decreasing time-since-fire (tables 3, 4, 5). These results complement the findings of previous studies that show a depletion of the soil seed store by fire (e.g., Meney *et al.* 1994, Pierce & Cowling 1991, Wilkinson & Jennings 1994). Our results show that the number of large native seeds in the soil is markedly lower in 17-year-old-burn sites compared to 45–year-old burn sites. These findings are very different to those of Koch *et al.* (2009), who reported recovery of the soil seed store within three years after fire, and a decline thereafter.

One explanation for the associations observed in the present study is the breaking of dormancy by heat or the chemicals in smoke. Non-viable seed accumulates after most soil seed germinates. Heat-initiated germination has been observed for *Lepidosperma* (Penman *et al.* 2008) and *Acacia* (Fryer 2006). Several species of *Astroloma* also respond to smoke as a germination cue (Fryer 2006), although this response has not been confirmed for *A. humifusum* Our viability data strongly suggest that germination of *A.*

TABLE 2
Mean number of seeds ± standard error (n) per 900 g (dry weight) soil at collection sites with and without plant taxa present in the above ground vegetation

Species	Present	Absent	F value	P value
Astroloma humifusum	7.9 ± 1.6 (26)	7.2 ± 1.3 (34)	0.10	0.749
Beyeria viscosa	2.5 ± 0.6 (25)	<0.1 ± 0.03 (35)	21.98	<0.001
Dodonea viscosa	1.4 ± 0.5 (44)	0.7 ± 0.3 (16)	0.70	0.405
Exocarpos cupressiformis	7.4 ± 3.6 (20)	3.6 ± 1.8 (40)	1.17	0.285
Lepidosperma laterale	0.4 ± 0.2 (28)	1.0 ± 0.7 (32)	0.58	0.449
Rubus fruticosus	0.0 ± 0.0 (57)	0.7 ± 0.2 (3)	0.58	0.450

TABLE 3
Results of general linear model analyses for seed number

Response/fixed variable	Fixed variable		Random variables				R^2 (%)
			Vegetation type		Floristic group		
	F	P	F	P	F	P	
Native/fires[1]	6.01	**0.001**	1.43	0.239	3.29	**0.019**	59.26
Native/tsf[2]	5.30	**0.001**	0.91	0.464	4.23	**0.005**	57.58
Exotic/fires	4.99	**0.002**	0.72	0.583	2.05	0.103	45.82
Exotic/tsf	4.98	**0.002**	0.91	0.464	2.89	**0.032**	45.79
Acacia spp./fires	0.88	0.485	0.32	0.865	0.83	0.511	18.18
Acacia spp./tsf	0.89	0.476	0.33	0.857	0.91	0.463	18.28
Astroloma humifusum/fires	3.29	**0.019**	2.16	0.088	0.79	0.541	33.16
Astroloma humifusum/tsf	1.67	0.174	0.93	0.454	0.59	0.674	25.07
Beyeria viscosa/fires	1.58	0.195	0.09	0.984	0.95	0.441	49.94
Beyeria viscosa/tsf	1.56	0.201	0.07	0.991	0.94	0.451	49.84
Dodonea viscosa/ fires	1.96	0.115	1.05	0.392	3.44	**0.015**	56.26
Dodonea viscosa/tsf	1.91	0.125	1.18	0.332	6.29	**<0.001**	56.07
Exocarpos cupressiformis/fires	6.21	**<0.001**	0.07	0.992	1.69	0.168	52.16
Exocarpos cupressiformis/tsf	6.21	**<0.001**	0.08	0.989	1.89	0.128	52.17
Lepidosperma laterale/fires	0.81	0.527	0.04	0.997	1.44	0.235	21.82
Lepidosperma laterale/tsf	0.83	0.513	0.05	0.995	1.44	0.237	21.95
Rubus fruticosus/fires	2.67	**0.044**	1.05	0.394	2.03	0.105	48.72
Rubus fruticosus/tsf	2.48	0.057	0.89	0.476	2.91	**0.031**	48.04

[1] Fires = number of fires since 1960, [2] tsf = time since last fire.

TABLE 4
Means and standard errors for seed number related to number of fires (1960–2012)

No. of fires	n	Native	Exotic	*A. humifusum*	*E. cupressiformis*	*R. fruticosus*
0	10	35.5 ± 9.1 A	12.2 ± 9.9 A	3.4 ± 1.9 A	23.3 ± 7.7 A	1.2 ± 0.6 AB
1	10	22.3 ± 5.3 AB	3.8 ± 1.4 A	11.5 ± 3.0 A	4.1 ± 1.9 B	2.4 ± 0.9 A
2	10	14.7 ± 2.0 B	0.7 ± 0.4 A	10.1 ± 2.1 A	1.2 ± 0.5 B	0.6 ± 0.3 AB
3	20	9.30 ± 1.8 B	0.5 ± 0.2 A	7.3 ± 1.8 A	0.4 ± 0.2 B	0.0 ± 0.0 B
5	10	6.10 ± 1.9 B	0.4 ± 0.2 A	5.4 ± 1.7 A	0.0 ± 0.0 B	0.1 ± 0.1 B

TABLE 5
Means and standard errors for seed number related to time-since-fire

Time-since-fire (years)	n	Native	Exotic	*E. cupressiformis*
c. 60	10	35.5 ± 9.1 A	12.2 ± 9.9 A	23.3 ± 7.7 A
45	10	22.3 ± 5.3 AB	3.8 ± 1.4 A	4.1 ± 1.9 B
17	20	12.1 ± 1.9 B	0.6 ± 0.2 A	0.7 ± 0.3 B
14	10	9.0 ± 2.0 B	0.4 ± 0.3 A	0.6 ± 0.3 B
6	20	6.1 ± 1.9 B	0.4 ± 0.2 A	0.0 ± 0.0 B

TABLE 6
Results of general linear model analyses for the viability (%) of seed of selected species

Response/fixed variable	Fixed variable		Random variables				R^2 (%)
			Vegetation type		Floristic group		
	F	P	F	P	F	P	
Native/fires[1]	1.33	0.275	0.17	0.953	5.81	**0.001**	71.06
Native/tsf[2]	1.33	0.275	0.19	0.942	6.46	**<0.001**	71.02
Acacia spp./fires	0.28	0.883	0.56	0.696	0.67	0.616	20.07
Acacia spp./tsf	0.82	0.554	0.59	0.671	0.72	0.584	20.37
Astroloma humifusum/fires	3.48	**0.016**	0.28	0.889	2.01	0.109	30.58
Astroloma humifusum/tsf	3.60	**0.014**	0.85	0.438	2.19	0.084	32.72
Exocarpos cupressiformis/fires	0.41	0.746	0.06	0.992	2.76	**0.038**	69.78
Exocarpos cupressiformis/tsf	0.41	0.746	0.06	0.993	2.76	**0.038**	69.84

[1] Number of fires since 1960, [2] tsf = time since last fire.

TABLE 7
Means and standard errors (n) of seed viability (%) related to number of fires (1960–2012)

No. of fires	*A. humifusum*	*Acacia* spp.	*B. viscosa*	*D. viscosa*	*E. cupressiformis*	Natives
0	53.3 ± 17.4 (7) A	81.9 ± 11.9 (4) A	60.9 ± 13.0 (9) A	100.0 ± 0.0 (8) A	31.7 ± 6.8 (10) A	46.8 ± 7.7 (10) A
1	24.0 ± 7.2 (10) AB	90.0 ± 10.0 (4) A	63.1 ± 15.0 (8) A	74.1 ± 14.0 (7) A	28.3 ± 10.0 (8) A	36.9 ± 6.6 (10) AB
2	19.8 ± 5.2 (10) B	75.0 ± 25.0 (4) A	–	70.6 ± 16.1 (6) A	28.6 ± 18.4 (7) A	33.0 ± 4.9 (10) AB
3	13.7 ± 3.4 (16) B	66.7 ± 23.6 (4) A	–	100.0 ± 0.0 (4) A	0.0 ± 0.0 (3) A	19.7 ± 6.0 (19) B
5	6.2 ± 6.2 (8) B	66.7 ± 33.3 (3) A	–	100.0 ± 0.0 (1) A		13.9 ± 6.7 (8) B

TABLE 8
Means and standard errors (n) of seed viability (%) related to time-since-fire (years)

Time-since-fire	*A. humifusum*	*Acacia* spp.	*B. viscosa*	*D. viscosa*	*E. cupressiformis*	Natives
50	53.3 ± 17.4 (7) A	81.9 ± 11.9 (4) A	60.9 ± 13.0 (9) A	100.0 ± 0.0 (8) A	31.7 ± 6.8 (10) A	46.8 ± 7.7 (10) A
45	24.0 ± 7.2 (10) AB	90.0 ± 10.0 (4) A	63.1 ± 15.0 (8) A	74.1 ± 14.0 (7) A	28.3 ± 10.0 (8) A	36.9 ± 6.6 (10) AB
17	19.2 ± 3.7 (17) B	77.8 ± 16.5 (6) A	–	82.4 ± 10.4 (10) A	28.6 ± 18.4 (7) A	31.6 ± 5.6 (19) AB
14	10.2 ± 3.9 (9) B	50.0 ± 50.0 (2) A	–	–	0.0 ± 0.0 (3) A	10.5 ± 4.5 (10) B
6	6.2 ± 6.2 (8) B	66.7 ± 33.3 (3) A	–	100.0 ± 0.0 (1) A	–	13.9 ± 6.7 (8) B

humifusum is stimulated by fire. Hodgkinson & Oxley (1990) found that germinability in *D. viscosa* increased when placed in boiling water for five seconds, but seed was killed by slow burning litter fires when temperatures exceeded 80°C.

Species that do not germinate in response to fire, like *E. cupressiformis*, could lose soil seed through overheating. However, the effect of reduction in seed input consequent upon cessation of reproductive activity while individuals recover vegetatively from fire may be a more substantial influence on seed numbers. *Exocarpos cupressiformis* and *D. viscosa* are heavily grazed by macropods (JBK, personal observation), which may inhibit their establishment after fires create green pick. Infrequently burned areas have greater densities of these species than more frequently burned areas. Purdie & Slatyer (1976) note that post-burn populations of *A. humifusum* are smaller than pre-burn populations, therefore the decrease in seed numbers for this species may also be related to smaller population sizes in more frequently burnt areas. More frequent fires equate to shorter inter-fire intervals. Therefore, insufficient time to set seed may explain low seed abundance. To allow successful flowering and seed set, Benson (1985) recommends a minimum fire-free period of nine to 10 years for eucalypt-dominated scleromorphic vegetation.

Bekker *et al.* (1998) found a strong negative correlation between seed longevity and the depth distribution of seeds, indicating that seed longevity is reduced in the surface layer. The heat associated with fire destroys organic matter (Humphreys & Craig 1981) and contributes to deterioration of porosity and increased erosivity (Certini 2005). Thus fire can be linked to soil compaction and reduced incorporation of seeds into the soil. This may partially explain the reduced viability in native and *A. humifusum* seeds in the areas burnt more frequently. That *Acacia* and *D. viscosa* were not affected in a similar manner may be explained by the dispersal of *Acacia* seeds into lower soil layers by ants, and by the small size of *D. viscosa* seeds, as smaller seeds are more likely to work their way down soil cracks (Bekker *et al.* 1998).

The conservation significance of the fire-related seed bank dynamics intimated by our data varies between the obligate seeder species and those with capacity for vegetative recovery from disturbance. As resprouters, as well as contributors to a persistent seed bank, species such as *E. cupressiformis* and *A. humifusum* are doubly buffered against disturbance or the lack thereof. Thus, *A. humifusum* can survive fire by resprouting, and survive elimination in the vegetation by light competition through its soil seed store, whereas the obligate seed regenerators *D. viscosa* and *B. viscosa* might be eliminated from an area if frequent fires exhaust their seed banks. Our data suggest that at least one major weed species, *R. fruticosus*, builds up its seed store as time elapses after fire. Such a mechanism may account for the prominence of exotic shrubs in long unburnt bush (Watson *et al.* 2009). There may thus be a tradeoff between maintaining obligate seeding natives and mitigating weed invasion. In the case of our study area, an interval between fires of less than 11 years is likely to lead to the elimination of *D. viscosa*, which takes this time after germination to release seed into the soil store (JBK, personal observation).

CONCLUSION

Ours is the first study of the effects of fire history on the soil seed bank of large-seeded geosporous species in a Tasmanian scleromorphic ecosystem. Out of six native large-seeded species the abundance of two species, *Astroloma humifusum* and *Exocarpos cupressiformis*, generally declined in the seedbank with more frequent and recent fire. This may be due to germination triggered by fire, selection against these species by fire, insufficient maturation periods between fire and reduced total seed output and population size due to repeated burning. A significant reduction in seed viability in natives and *A. humifusum* was also related to fire history, possibly reflecting loss of viable seed to germination.

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APPENDIX 1
Characteristics of seed types

Species	Description
Exocarpos cupressiformis	ovoid and dark brown, with three suture lines on top
Dodonea viscosa	globular, black and shiny, with a flattened rim (pl. 1F)
Astroloma humifusum	trigonous seeds contained within a woody, multi-chambered, ellipsoid capsule with longitudinal furrows (pl. 1D)
Lepidosperma laterale	ellipsoid with brown casing, white when casing removed, and with a capitate embryo (pl. 2F)
Beyeria viscosa	oblong with a flat face at the attachment end (pl. 1E)
Acacia spp.	seeds variably black, shiny, obovate or oblong (pl. 1A–C)
Rubus fruticosus	triangular and flattened along radial axis, tan to light brown, with a reticulate surface
Passiflora tarminiana [1]	cordiform, dark brown, with a pitted surface (pl. 2D)
Vicia sp. [1]	globular with a smooth speckled brown and green surface, and a distinctive hilum (pl. 2E)
Galium sp. [1]	spheroidal, dark brown, with finely netted ridges and a deeply depressed hilum (pl. 2C)
Plantago sp. [1]	elongate, with longitudinal faces and characteristic side-attachment (pl. 2A)
Cotoneaster sp. [1]	ovate, widest at the attachment end, with one flattened face, light brown to tan, with some retaining the peduncle (pl. 2B)
exotic seed 1 [1]	variably spheroid, woody, with a single chamber
exotic seed 2 [1]	large, woody, with the two halves overlapping

[1] exotic taxon

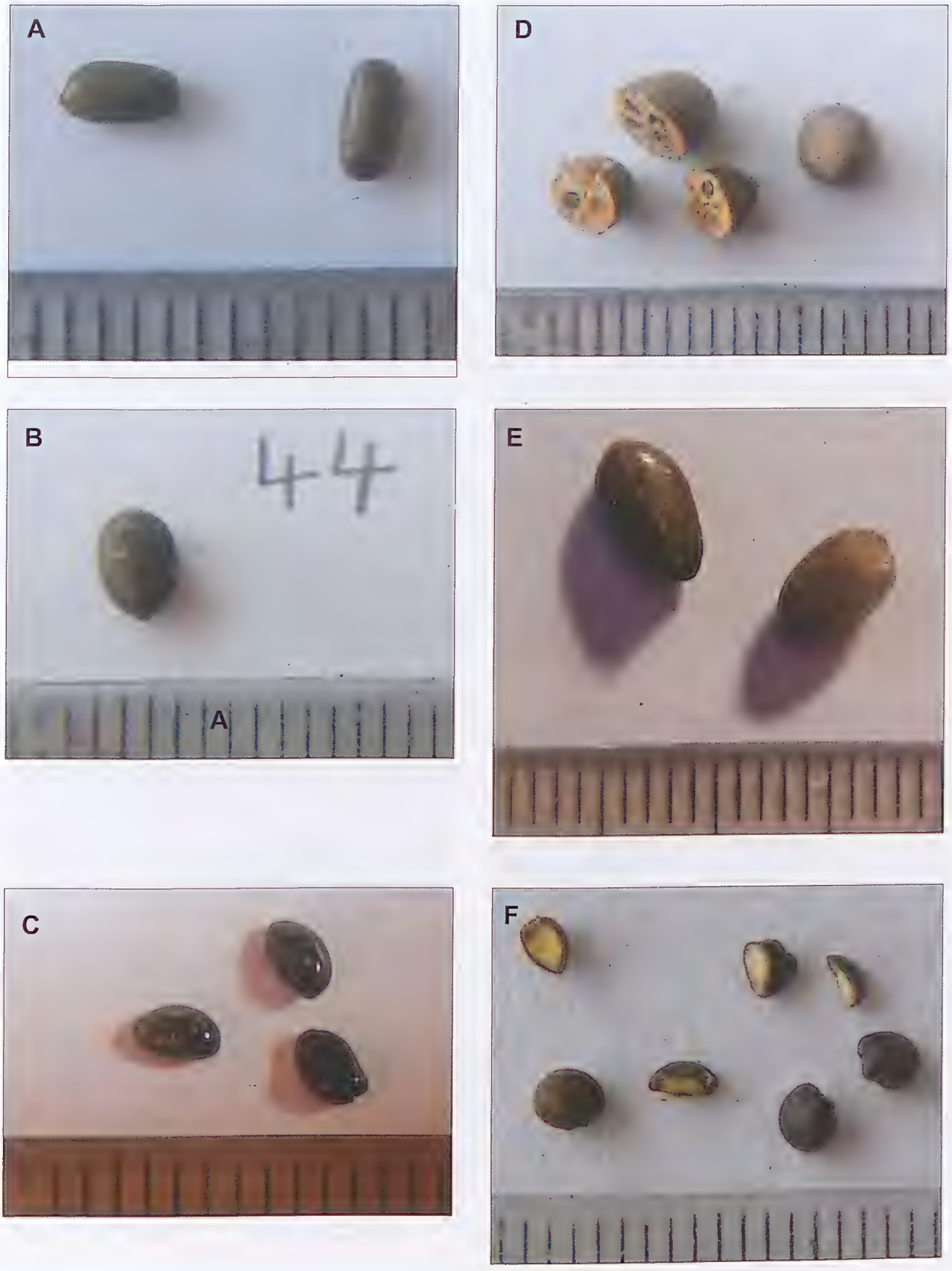

PLATE 1
(A) Acacia *sp. 1; (B)* Acacia *sp. 2; (C)* Acacia *sp. 3; (D)* Astroloma humifusum*; (E)* Beyeria viscosa*; (F)* Dodonea viscosa. *Scales in millimetres.*

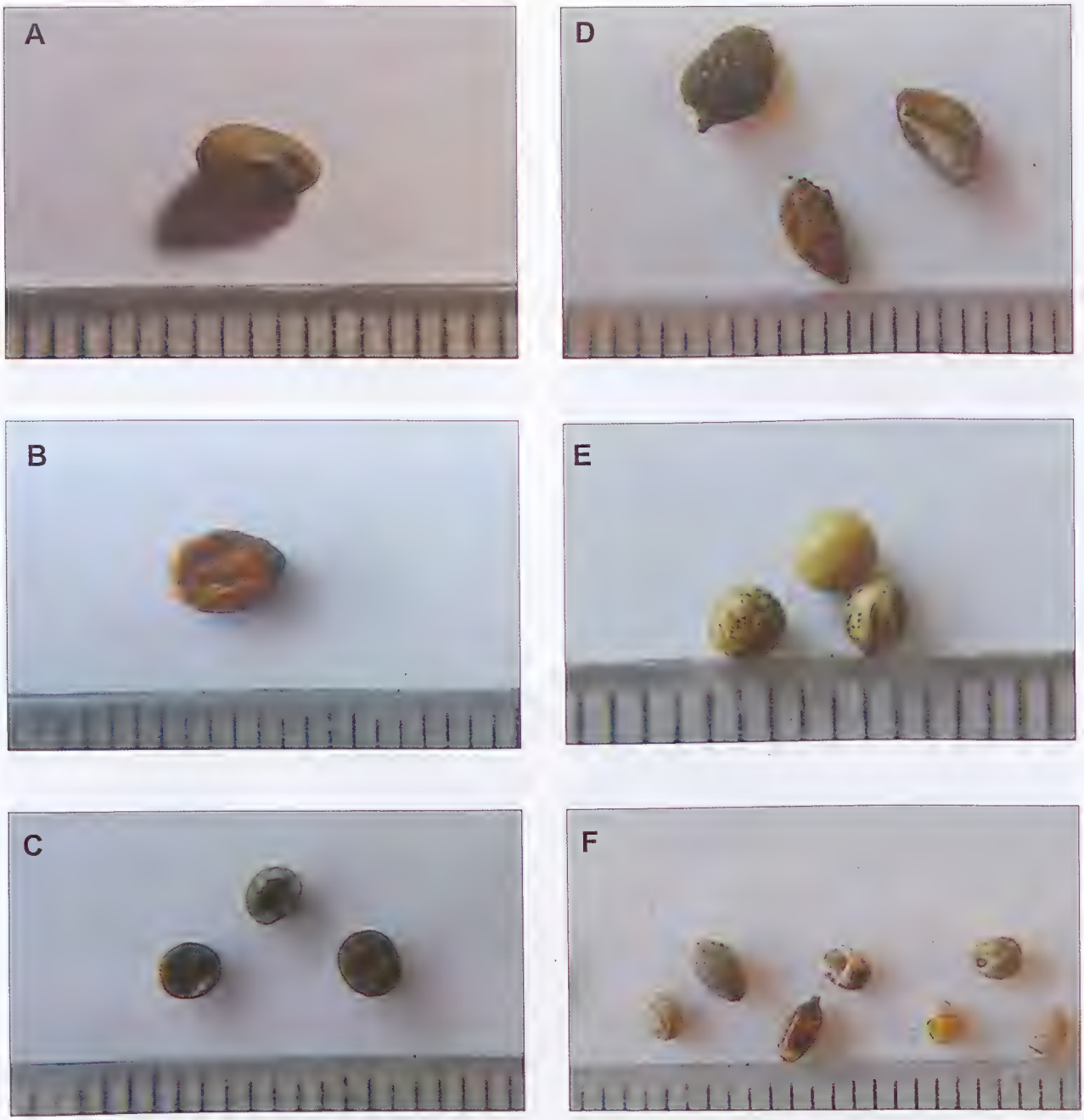

PLATE 2
(A) Plantago lanceolata; *(B)* Cotoneaster *sp.; (C)* Galium *sp.; (D)* Passiflora tarminiana*; (E)* Vicia *sp.; (F)* Lepidosperma laterale. *Scales in millimetres.*

AGE AND PALAEOENVIRONMENT OF PLIOCENE SEDIMENTS, CAMERON INLET FORMATION, EASTERN FLINDERS ISLAND, TASMANIA: IMPLICATIONS FOR SOUTHEASTERN AUSTRALIAN BIOSTRATIGRAPHY

by Patrick G. Quilty, Jason Whitehead and Dale Lewis

(with seven text-figures, four plates, one appendix and one appendix table)

Quilty, P.G., Whitehead, J. & Lewis, D. 2013 (17:xii): Age and palaeoenvironment of Pliocene sediments, Cameron Inlet Formation, eastern Flinders Island, Tasmania: implications for southeastern Australian biostratigraphy. *Papers and Proceedings of the Royal Society of Tasmania* 147: 51–83. ISSN 0080-4703. School of Earth Sciences, University of Tasmania, Private Bag 79, Hobart, Tasmania 7001, Australia, and Institute for Marine and Antarctic Studies (IMAS), Private Bag 129, Hobart, Tasmania 7001, Australia (PGQ*); Institute for Antarctic and Southern Ocean Studies (IASOS), University of Tasmania, Private Bag 77, Hobart, Tasmania 7001, Australia (JW); School of Earth Sciences, University of Tasmania, Private Bag 79, Hobart, Tasmania 7001 (DL).
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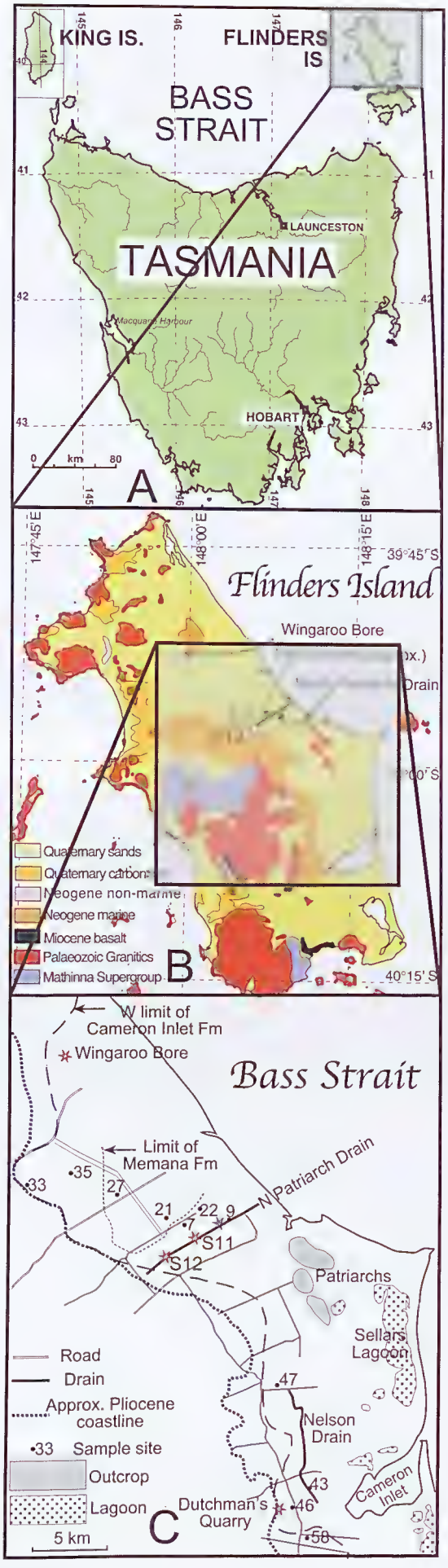
A previously unrecorded thin unit of very Early Pliocene calcareous sediments of the Cameron Inlet Formation from two auger holes in central Flinders Island, Tasmania, has yielded a very diverse fauna of benthic Foraminifera and enough planktonic forms to allow fine correlation with international biostratigraphic standards (N19, approximately 5.3–4.4 Ma, or Lower Opoitian in New Zealand terminology). Ostracods are also recorded. It is older than an earlier recorded sample from North Patriarch Drain a few kilometres away. It lies within the Kalimnan of southeastern Australian stage nomenclature and probably equivalent to 1985 Molluscan Assemblage XVI. The sediments and faunas accumulated in very shallow, fully marine conditions, initially with some possible estuarine aspect that faded with time. The fauna is of well-known species, dominated by *Parredicta kalimnensis* (Parr, 1939). Other abundant and diverse forms are elphidiids and cibicidids. Agglutinated forms are almost absent and miliolids are diverse but minor components. The fauna includes a new polymorphinid genus and species that will be described elsewhere. The samples contain a bewildering array of unilocular forms. Water temperature appears to have been about 12°C. The Kalimnan Stage may encompass the entire Pliocene and two substages may be identifiable.
Key Words: Pliocene, Flinders Island, Foraminifera, ostracods, Cameron Inlet Formation, Kalimnan.

INTRODUCTION

The Pliocene was a very significant time in global history resulting in major re-organisation of the world's oceanographic circulation and its consequences. The emergence of the Isthmus of Panama halted the flow of marine waters from the Atlantic Ocean to the Pacific Ocean (Haug *et al.* 2001, Schmidt 2007, Sarnthein *et al.* 2009), in turn strengthening the flow of the Gulf Stream to the north and causing initiation of the sequence of oscillating northern hemisphere ice sheets controlled in detail by orbital forcing – the Milankovich cycles. There is evidence of major extinctions and radiations in the marine environment at some time approximately in the Late Miocene to mid-Pliocene (Berkman & Prentice 1996, Bargelloni *et al.* 1997, Fordyce & de Muizon 2001, Fordyce *et al.* 2002, Fulton & Strobeck 2010, Chen *et al.* 2011), and subsequent effects worldwide, typified by the hypothesis of an impact on aridification in east Africa (Cane & Molnar 2001) but there is scope for considerable improvement in the understanding of the scale and timing of these changes. It is not clear how directly these changes affected oceanography in southeastern Australia. Much of this change occurred during the time of deposition of sedimentary successions recorded in this paper.

Flinders Island (fig. 1A–C) contains as yet poorly understood marine Pliocene sediments that contribute to our knowledge of the evolution of biostratigraphy and palaeoenvionment of southeastern Australia during this critical time. The island is 65 km long (N–S), 40 km wide (E–W) and 1333 km² in surface area, in eastern Bass Strait on the shallow continental shelf between southeastern Australia and the mainland of Tasmania (fig. 1A). It is the largest island of the Furneaux Group in Bass Strait, the exposed part of the Bassian Rise between Bass Basin to the west and Gippsland Basin to the east (e.g., Thompson 1986). On the western half of the island, Ordovician-Devonian sedimentary rocks of the Mathinna Supergroup (fig. 1B) are intruded by Devonian granitic rocks and form an elevated ridge ≤ 756 m in altitude. On the eastern half of the island are granitic hills (Patriarchs), isolated from the main western ridge and surrounded by coastal plain that consists of marine sediments of Pliocene and Pleistocene age, largely overlain by Quaternary lagoon sediments, alluvium and soils. Early Miocene basalt outcrops (20 ± 2.7 Ma; Zwingmann *et al.* 2004) in the south of the island and marks the southwestern extent of Cenozoic sediments. Magnetic data suggest that basalt underlies much of the Pliocene and younger sedimentary sequence on the eastern part of the island (J. Everard pers. comm. 29 May 2013). The Pliocene sediments belong to the Dutchman Coquinoid Limestone, and the Cameron Inlet Formation (CIF) that occur up to 32 m altitude and are presumed to cover an area of ~150 km². There is little or no sub-aerial outcrop and the formations are normally exposed in farm dams, agricultural drainage trenches, and in underwater outcrops to the east of the island. It is perhaps convenient to consider the marine Neogene sequence of eastern Flinders Island, studied here, as marking the southwestern onshore margin of the marine Cenozoic section of the Gippsland Basin (Maung & Nicholas 1990).



This study revises the sedimentology, lithostratigraphy and foraminiferal biostratigraphy of the CIF based on a recently sampled section of age older than recorded previously. The sections studied are rich in microfossils and the Foraminifera and ostracods provide ample evidence for the age and environment of deposition of this material using quantitative foraminiferal and ostracod data.

PREVIOUS STUDIES

The earliest records of Pliocene sediments on the island were probably by Johnston (1879), who referred to deposits on several islands in the area, and Singleton (1941) who listed them from ?Wingaroo Bore (fig. 1B).

R.W.T. Wilkins (quoted p. 235 in Spry & Banks 1962, and Sutherland & Kershaw 1971) stated that: "On the eastern side of Flinders Island are two formations of probably post-Kalimnan, pre-Maretimo age. Kalimnan is Lower Pliocene and the Maretimo Member in Victoria is probably uppermost Pliocene. The formations contain suites of mollusca [sic], and appear to be approximate lateral equivalents. … The Cameron Inlet Marl is a green, glauconitic, shelly marl outcropping in the floor of the Nelson Lagoon drain". The two formations are the Cameron Inlet Marl and the Dutchman Coquinoid Limestone. Wilkins further suggested a mid to Late Pliocene age on the basis of the molluscan fauna and thus probably post-Kalimnan, pre-Maretimo age, while noting that the molluscs "have a very strong Kalimnan aspect". That report can be interpreted as allowing the possibility of two distinct units with different molluscan (and, by extension, foraminiferal) faunas. Darragh 1971 (in Sutherland & Kershaw 1971) listed molluscs from strata that belong to the two formations and the faunas are different, consistent with the foraminiferal data generated here. The Pliocene units are overlain by various other, younger, stratigraphic units. In the North Patriarch Drain section, they are the Memana Formation and Petibela Sand (Dimmock 1957) (fig. 2). The Memana Formation is marine and possibly of Lower Pleistocene (Werrikooian) age on the basis of its mollusc fauna, and the widespread Petibela Sand is non-marine.

The Cenozoic geology of the island was reviewed by Sutherland & Kershaw (1971) who showed that the late Cenozoic stratigraphy is complex, marking a variety of advances and retreats of the sea generating a series of thin units both marine and non-marine, and leading to recycling of molluscs and possibly Foraminifera from marine into non-marine sediments. There is, to date, no record of Cenozoic marine sediments older than the Pliocene on the island but Sutherland & Kershaw (1971) referred to possible records of recycled older Foraminifera and Miocene faunas recorded from nearby Preservation Island (Quilty 1972). Sutherland & Kershaw (1971) discussed each of the known stratigraphic units and provided the understanding of the geology of the island as then, and now, known with a comprehensive list of the molluscs from various units including the CIF. They also noted a few species of Foraminifera and commented

FIG. 1 — Locality map. Sections studied in detail are from North Patriarch Drain (1985), S11 and S12. (A) General locality map. (B, C) Details of sample sites mentioned in text. Red stars indicate important sites. Blue star – North Patriarch Drain (1985).

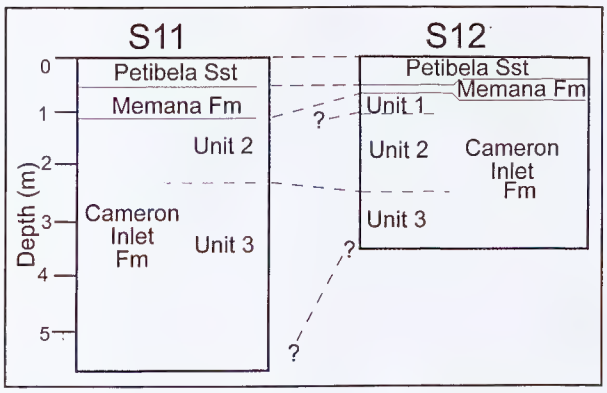


FIG. 2.— Lithostratigraphy of sections S11 and S12

that it accumulated in a shallow-water, nearshore but open ocean environment. They showed that the thickness may exceed 7.5 m.

Quilty (1985) recorded a fauna from a single sample from the North Patriarch Drain on Flinders Island (fig. 1C), about 2 km from the location of the sections studied here. It is referred to here as NPD1985. The presence of *Globorotalia inflata* (d'Orbigny, 1839), *G. crassaformis* (Galloway & Wissler, 1927), *Globigerina bulloides* d'Orbigny, 1826 and *G. rubescens decoraperta* Takayanagi & Saito, 1962 allowed correlation with the Blow (1969) N20 or N21 planktonic foraminiferal zones indicating a mid- to Late Pliocene age. However, the mollusc biostratigraphy was revised and the age constrained to the Late Pliocene (Darragh 1985). Amino acid racemisation dating of molluscs provided relative age results younger than anticipated for the Pliocene. This is thought to be due to *in situ* leaching of the molluscs (Murray-Wallace & Goede 1995). While many of the major species of Foraminifera are in common with the sections studied here, the lesser species, while diverse, are very different, reflecting marked environmentally controlled differences. In the sample recorded by Quilty (1985), using the concepts introduced by Walton (1964), dominance was much lower (7.5%), diversity higher (60) and planktonic percentage much higher at 29% than in samples of this study, all suggestive of significantly deeper water deposition (approximately inner-mid-continental shelf) in marked contrast with the very shallow water indications of the present study.

Palaeotemperature reconstructions from isotope measurements of *Ostrea* sp. shells from Dutchman's Quarry (fig. 1C) imply that the Pliocene annual mean sea surface temperature around Flinders Island was 16.5°C (Dorman 1966), one degree warmer than current (15.6°C). The Dutchman's Quarry and Nelson Drain outcrops were correlated through similarities in mollusc faunas and the strata renamed the Cameron Inlet Formation (Darragh & Kendrick 1971).

STRATIGRAPHIC SETTING

The CIF was described initially from outcrops in the Dutchman's Quarry (i.e., Dutchman Coquinoid Limestone) and Nelson Drain (i.e., Cameron Inlet Marl), where its lithology varies from glauconitic calcareous sand, silt, gravel, shell coquina and marl (Wilkins 1962) (fig. 2). Sutherland & Kershaw (1971) mapped the extent of the Formation and described a 0.6-m-thick type section at Nelson Drain (fig. 1C) consisting of green glauconitic shelly marl that contains different mollusc horizons. Other sections include 0.8 km north of East River (0.52 m thick), Dutchman's Quarry (1.2 m), and Wingaroo Bore (~7 m; 17–24 m below ground surface). North of East River, the exposed portion of the formation consists of a lowermost 15 cm shelly sand bed (Unit d), overlain by 30 cm sand bed (Unit e), and a 7.5-cm-thick fossiliferous green glauconitic marl (Unit f) (Sutherland & Kershaw 1971). Similar units were also identified at the Dutchman's Quarry, but contained more silt, and were thought to be deeper water deposits. The Cameron Inlet Marl (Unit f) appears to correlate laterally throughout the above outcrops. At the Wingaroo Bore location the CIF consists of fossiliferous sand and muddy sand deposited in a semi-sheltered bay. A mid- to Late Pliocene age was assigned to the formation based upon the presence of the fossil echinoid *Lovenia* sp. and the bivalve *Cucullaea* sp. The mollusc fauna suggests that some facies have been deposited in a lagoon or nearshore marine environment. Some sediment horizons contain broken mollusc fossils, suggesting some re-working in shallow water, and eroded and bored shells, indicating some aerial exposure. However, the moderate percentage of planktonic to benthic Foraminifera in NPD1985 relates to a period of deposition in a deeper, inner continental shelf environment (Taylor 1971 in Sutherland & Kershaw 1971). Other fossils found in the CIF include corals, whale vertebrae, a whale skull of a form of the genus *Ziphius*, and fish teeth including those of the large shark *Carcharodon megalodon* Agassiz, 1843 (Sutherland & Kershaw 1971, Fordyce 1982).

Early Pleistocene marine sediments of the Memana Formation overlie the CIF in the northeastern region of the coastal plain (Sutherland & Kershaw 1971). The Memana Formation was distinguished from the CIF by the presence of the mollusc *Zenatiopsis ultima* (Darragh & Kendrick, 1971). Some reworked Pliocene shells from the CIF also occur in the basal member of the Memana Formation. Pleistocene fossiliferous marine sediments of the East River Coquina (Sutherland & Kershaw 1971) overlie the eastern extent of the CIF. The few natural exposures of these marine sediments of different age are due to an overlying cover of Pleistocene sands (Nala and Petibela Sands), aeolian limestones (Palana Limestone) and Quaternary to Recent lagoon deposits.

The Petibela Sand has been documented previously as aeolian in origin (Sutherland & Kershaw 1971); however, at Site S12 (fig. 1), what could perhaps be interpreted as the Petibela Sand overlying of the CIF, contains a bed of molluscs (*Katelysia* sp.) that were deposited during a marine incursion in the Pleistocene. The mollusc valves have been separated and oriented with their concave inner surfaces facing downward, as a result of past water current or wave action. The molluscs indicate that this may belong to the Upper Pleistocene East River Coquina, which outcrops in Nelson Drain area ~12 km farther south (fig. 1C). A sand bed beneath the *Katelysia* sp. bed overlies the CIF to the northwest. The Petibela Sand may in turn overly the East River Coquina.

Three units (3, 2 and 1) are recognisable within the CIF (figs 2, 5). Lithology coarsens upwards from Unit 3 to Unit 2 (which may represent a regressive sea level sequence or a change to shallower basin conditions due to sediment infilling) but these units are overlain by Unit 1 of marl representing deposition in quiet waters. This facies succession corresponds with a transition from a shallow

open marine (Unit 3) through shallower conditions or sand bar development (Unit 2) to quiet coastal lagoon or deeper water conditions (Unit 1). There is virtually no change in planktonic Foraminifera from Unit 3 to shallow Units 2 and 1. Whale fossil remains appear to be more prevalent within Unit 3. Sutherland & Kershaw (1971) described a coarser facies variation within Unit 1 to the northwest and have interpreted this as representing a littoral inshore environment in contrast to deeper depositional conditions to the east.

New fieldwork shows that the CIF contains abundant *Ostrea* sp. (at Sites 33, 32 and 27; fig. 1C), and *Glycymeris* sp. (Sites 35, 30A, 30B, 30C and 16A). *In situ* and articulated *Ostrea* sp. occurs at Site 33 (elevation 32 m). Sites 35 and 32 appear more diverse in mollusc species than other sites from the northwestern extent of the formation. This region of the formation typically lacks *Eucrassatella* sp. and *Cucullaea* sp. that are abundant elsewhere on the island within fossiliferous marl exposures. Only an individual reworked *Eucrassatella* sp. hinge was found at Site 27. Augers were attempted at other sites but were unsuccessful due to the presence of impenetrable coarse shell horizons (Sites 32, 30B and 15) or lithified coarse sand layers (Sites 27 and 16a). The occurrence of *Amoria undulata* (Lamarck, 1804) and *Polinices* aff. *cunninghamensis* at these sites suggests that these strata belong to the CIF and are not part of the nearby Pleistocene Memana Formation. The Memana Formation is absent at Site 9 due to a disconformity but is typically overlain by Petibela Sand (Sutherland & Kershaw 1971). The northwestern region of the CIF is generally overlain by a grey sand unit which, in turn, is overlain by Lower Pleistocene Palana Limestone.

MATERIAL AND METHODS

Post-1970 pastoral expansion with dam and drain construction, has increased the exposed extent of the CIF a few kilometres farther north of that mapped by Sutherland & Kershaw (1971). Field identification of the formation in this region was possible from the presence of *in situ* and articulated, or abundant, Pliocene mollusc fossils, as in Sutherland & Kershaw (1971).

Lithological data were collected in a west to east transect over the northern extent of the CIF at Sites 11, 12 and 22, from which three lithological units can be identified (fig. 2).

Unit 1 (upper unit): Calcareous glauconitic green to grey sandy marl. This lithified to semi-lithified unit typically contains *in situ* articulated molluscs. The unit is ~50 cm thick.

Unit 2 (middle unit): A grey, tan or brown unlithified, dominantly of shell fragments, and crystal quartz sand. The unit is ~120 cm thick.

Unit 3 (lower unit): Grey sandy silt with occasional shell fragments or shell layers. The unit is ~290 cm thick.

Samples were taken in 5 cm bulk intervals through the exposed sections for microfossil analysis. At several locations sub-surface sediments were also obtained using a hand auger to obtain samples from a depth of ~4 m. Exposure and auger samples were collected from Sites 12, 11 and 9, in an east–west transect across the formation. The outer edge of the auger samples was removed to avoid any microfossil re-working during the augering process. The lithology was logged and again the samples divided into 5-cm-long intervals for microfossil analysis.

Foraminifera and ostracod data were collected from 32 samples from sites S11 and S12. Samples were prepared for microfossil analysis through sediment drying and sieving on an EFL 2mk3 Test Sieve Shaker for ~30 seconds, then gently sieved by hand. Microfossils were analysed from two sieve size fractions: 500–1000 μ and 500–150 μ. Approximately 400 Foraminifera were collected from the 150–500 μ fractions while all Foraminifera were collected from the 500–1000 μ fraction. The age of the Formation was revised using the foraminiferal zonations of Blow (1969), Kennett & Srinivasan (1983), Hornibrook (1982), Hornibrook *et al.* 1989) and Berggren *et al.* (1985). Benthic Foraminifera dominate and were identified dominantly by reference to Carter (1964), Hayward *et al.* (1997, 1999), Yassini & Jones (1995), Jones (1994) and Parr (1932, 1939, 1950). Ostracods were collected in conjunction with the Foraminifera, and constitute the first investigation of these in the formation. The quantitative data were standardised to represent total of microfossil abundance per gram of original unsieved sediment.

Samples were collected by augering by JW and termed Sections S11 and S12.

Locality:

S11 – 39°5.5'S; 148°00.9'E – (ER9276 on Universal Grid Reference, Grid Zone 55G)

S12 – 39°57'S; 148°01.1'E – (ER9474)

NPD1985 – 39°58'S; 148°07'E (ER93750)

JW picked the samples which were then passed to DL and PQ for identification of the ostracods and Foraminifera respectively. Because of the apparent difference in detail between the sample studied by Quilty (1985) and the more numerous and better-controlled samples studied here, the earlier sample was re-processed and the results refined and modernised. The fauna from the 1985 sample consists of those species resting on a 125-micron sieve. The ostracods from that sample were not studied.

Preservation varies markedly for specimens of many species even within the one sample. Agglutinated species are rare. The dominant larger forms of *Elphidium* and *Parredicta* commonly include highly damaged specimens although most are very well preserved. Nodosariid species are well preserved and show no evidence of high-energy damage. A striking feature is the abundance and diversity of unilocular species (pl. 1), and the variation in unilocular fauna from section to section. Miliolids generally are well preserved, and preservation of planktonic species is adequate. Preservation is better in samples from Section S12 and this is evident in the lower proportion of unidentified specimens.

Almost all species were subject to SEM imaging at the Central Science Laboratory (CSL), University of Tasmania.

Figured species (pls 1–4) are the planktonic forms, those benthics that are the major components or new or unusual records, and the unilocular forms because of their bewildering diversity. Figured specimens are held at the School of Earth Sciences, University of Tasmania, and the number following the inital UTGD on plate explanations is the accession number in that collection.

AGE AND CORRELATION

In Australian stage terms, the faunas from the NPD1985, and those recorded here, based on composition of the molluscan and benthic foraminiferid fauna, are Kalimnan (fig. 7), but

there are questions about exactly how the Kalimnan equates to international schemes.

Blow (1969) introduced his zonation employing the now commonly accepted P (Palaeogene) and N (Neogene) zones but many authors have experienced difficulty in applying consistently zones N18 (bridging the Miocene/Pliocene boundary), and N19-21, those of the Pliocene (Berggren *et al.* 1995). Recently the Pliocene/Pleistocene boundary has been reconsidered and is now taken as being at 2.59 Ma (Gibbard *et al.* 2009, ICS Subcommission on Quaternary Stratigraphy 2009), including much of N21, and thus some faunas earlier considered Late Pliocene may now be Pleistocene.

There is no satisfactory comprehensive local southeastern Australian zonation using planktonic species because few well-studied continuous sequences through this interval in the region have been published. Hornibrook (1982) provided a useful description of the sequence of *Globorotalia* in Deep Sea Drilling Project (DSDP) Site 284 at a similar latitude to the material studied here and lying in the Tasman Sea between Flinders Island and New Zealand, and Hornibrook *et al.* (1989) published the most useful regional review. This allows application of New Zealand stage terminology to the Flinders Island material. Otherwise, it has been necessary to identify species from a variety of authorities, including Blow (1969) and Kennett & Srinivasan (1983).

While planktonic species constitute only a small percentage of the foraminiferal faunas in S11 and S12, typically approximately 2%, the diversity represented probably contains the full range that inhabited the region at the time. The planktonic species are dominated by simple globigerinid forms such as *Globigerina bulloides* d'Orbigny, 1826 with a few *G. apertura* Cushman, 1918 and *G. woodi* Jenkins, 1960. Keeled *Globorotalia* are rare and restricted to *Globorotalia pliozea* Hornibrook, 1982 and *G. mons* Hornibrook, 1982 Most globorotalids are simple turborotalids (very dominantly *G. crassaformis* (Galloway & Wissler, 1927)—"rounded" in Hornibrook's (1982) terms and always sinistrally coiled) and *G. puncticulata* (Deshayes, 1832). No large heavily thickened keeled *Globorotalia* were identified and *Globoquadrina, Pulleniatina, Sphaeroidinella* (and related genera) are absent, consistent with other cool water indications of the fauna.

The S11/S12 sections appear to allow correlation with a very narrow interval at DSDP Site 284, particularly Cores 14 and 15 that lie on the Kapitean/Opoitian boundary, very early Pliocene. Hornibrook *et al.* (1989) reviewed New Zealand foraminiferal biostratigraphy with comprehensive range charts. The fauna here relates (Hornibrook *et al.* 1989, Table 5) to a narrow interval in the older half of the Opoitian, early to mid-N19, approximately 5.3–4.4.Ma, or early to mid-Zanclean in European terms. The older limit is imposed by the First Appearance Datum (FAD) of unkeeled *G. crassaformis* and *G. puncticulata* and the younger limit by the Last Appearance Datum (LAD) of *G. mons*.

Carter (1964) described the foraminiferal faunas of comparable age from the Gippsland Basin and included those from both Tambo River and Jemmys Point Formations. It is a moot point about correlation but from the foraminiferal species listed, it seems that sections S11 and S12 are correlates of the Jemmys Point Formation. The relationship with the Tambo River Formation is unclear.

Sutherland & Kershaw (1971) listed a few Foraminifera identified by A.C. Collins from the top of the CIF in the Dutchman's Quarry and included *Glandulina kalimnensis* Parr, 1939 *Rotalia* (as *Rotalina*) *hamiltonensis* Parr, 1939, *Nonion victoriensis* Cushman, 1936 and *Massilina lapidigera* (Howchin & Parr, 1938). This is a typical Kalimnan fauna. Of these, only *Pseudononion victoriensis* has been recorded in this study and is abundant in both NPD1985 and S11 and S12 sections. *Flintina intermedia* (Howchin, 1889) another Kalimnan species, is present in NPD1985 but has not been seen in the S11 and S12 sections. Other generic comments by Collins on the fauna at the Dutchman's Quarry are consistent with the general comments that can be made about the fauna in the NPD1985 sample.

Darragh (1985) described the sequence of 18 Mollusc Assemblage faunas in southeastern Australia and his Molluscan Faunas XV, XVI, XVII and XVIII are relevant to the timescale of the Flinders Island sections. Fauna XV is Cheltenhamian (Late Miocene, possibly Early Pliocene) and thus probably pre-dates the Flinders Island material. Fauna XVI is defined from the Jemmys Point Formation which is Early Pliocene (Kalimnan). Fauna XVII is defined from the CIF on Flinders Island and taken to be Late Pliocene. No southeastern Australian stage name is applicable. Fauna XVIII is regarded as Late Pliocene (now probably Early Pleistocene) Werrikooian. Unfortunately, the S11 and S12 sections have not been subject to mollusc study and at the time of writing, Darragh's CIF material had not had the foraminiferal data published (Quilty 1985), but that now seems also to be Late Pliocene in modern terms. It is likely that a mollusc fauna from S11/S12 would be equivalent to Assemblage XVI of the Jemmys Point Formation.

Abele *et al.* (1988) have provided the most comprehensive review of the stratigraphy of the Cenozoic of Victoria and the stage terminology employed on figure 7 is based on that summary.

It seems clear that the foraminiferal faunas from both NPD1985 and S11 and S12 sections, while of different ages in foraminiferal terms, can be referred to the Kalimnan. It perhaps follows that the CIF contains within it products of more than one episode of sedimentation covering much of the Pliocene (5.3–2.6 Ma). Another emerging possibility is that the Kalimnan may be divisible into early (characterised by Darragh's 1985 Mollusc Assemblage XVI) and late (characterised by Darragh's 1985 Mollusc Assemblage XVII) substages, both within the Pliocene.

The time of deposition of S11 and S12 corresponds very closely with Supercycle TB3, Cycle 3.4 of Haq *et al.* (1987) and the thinness of the unit suggests that it occurred at the peak of a transgression marked by that curve.

COMPARISON OF S11 AND S12 SECTIONS

As illustrated in figure 3, there is a clear contrast between dominance and diversity trends between the two sections, using dominance and diversity as defined by Walton (1964) and in change in planktonic foraminiferal content (fig. 4A, B). Section S11 has a higher variability in both dominance and diversity than is the case for section S12. Both sections were deposited in less than 10 fathoms (~20 m), using the criterion of dominance/diversity developed by Walton.

Although the sections are relatively close (2 km apart), and while species composition is very similar, there are marked differences in proportions of Foraminifera present, and there are changes that, while differing in detail, are interpreted as part of a consistent trend of increasing water

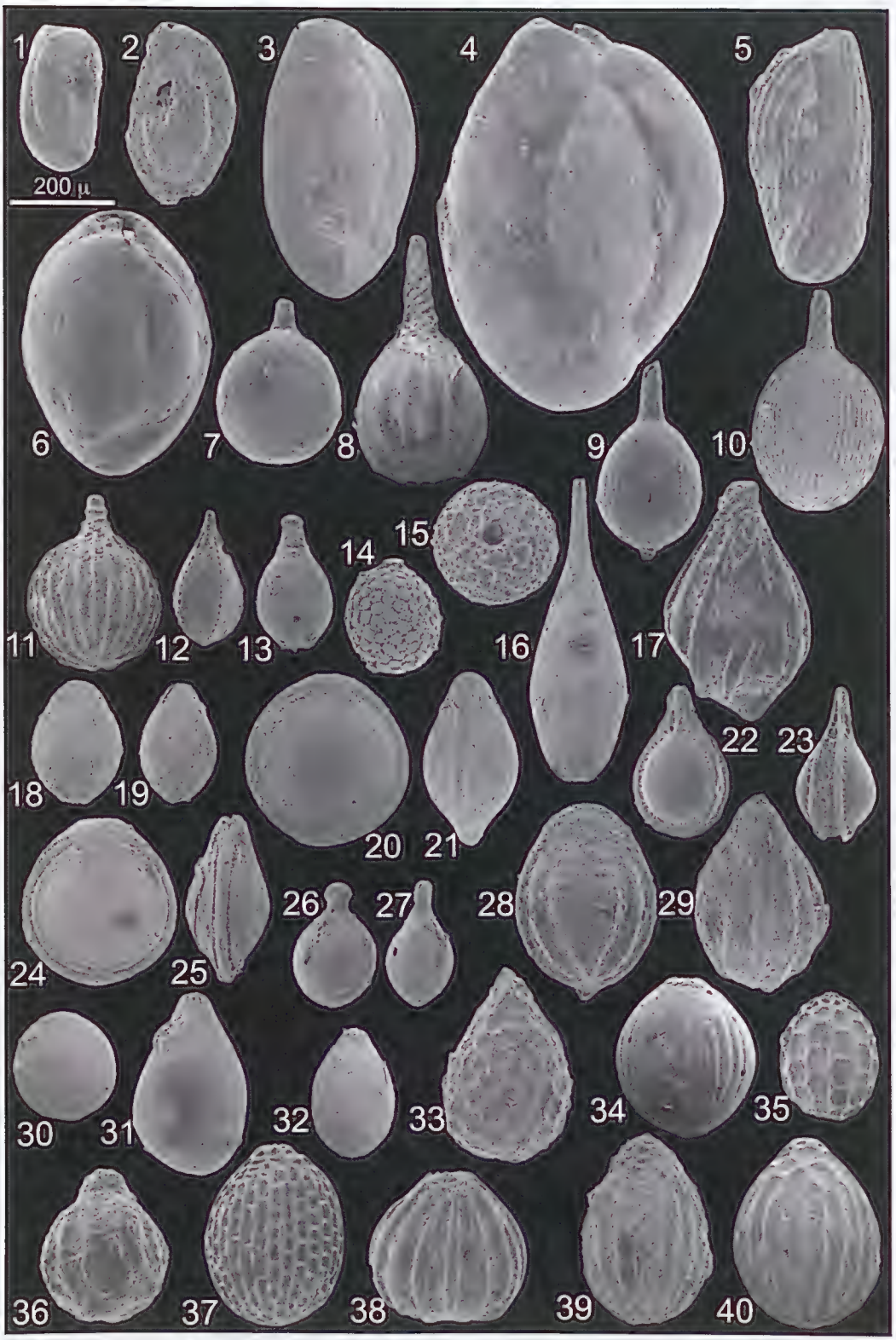


PLATE 1

Pliocene benthic Foraminifera, Flinders Island. 1. *Gordiospira* sp., UTGD128852. 2. *Quinqueloculina asperula* Seguenza 1862, UTGD128853. 3. *Q. oblonga* (Montagu 1803), UTGD128854. 4. *Q. seminulum* (Linné 1758), UTGD128855. 5. ?*Q. poeyana victoriensis* Collins 1974, UTGD128856. 6. *Triloculina trigonula* (Lamarck 1804), UTGD128857. 7. *Lagena flatulenta* Loeblich & Tappan 1953, UTGD128858. 8. *L. perlucida* (Montagu 1803), UTGD128859. 9. *L. striata paucistriata* Yassini & Jones 1995, UTGD128860. 10. *L. striatospirolata* Albani & Yassini 1989, UTGD128861. 11. *L. sulcata* (Walker & Jacob 1798), UTGD128862. 12. *L* sp. 1, UTGD128863. 13. *L.* sp. 2, UTGD128864. 14. *L.* sp. 3, UTGD128865. 15. ?*Lagena* sp., UTGD128866. 16. *Procerolagena clavata* (d'Orbigny 1846), UTGD128867. 17. *Cushmanina spiralis* (Brady 1884), UTGD128868. 18, 19. *Fissurina lucida* (Williamson 1848), UTGD128869. 20, 21. *F. marginata* (Montagu 1803), UTGD128870. 22, 23. *F. pacifica* Parr 1950, UTGD128871. 24, 25. *F.* sp. 1, UTGD128872. 26, 27. *F.* sp. 2, UTGD128873. 28, 29. *F.* sp. 3, UTGD128874. 30. *F.* sp. 4, UTGD128875. 31. *Oolina emaciata* (Reuss 1862), UTGD128876. 32. *O. globosa* (Montagu 1803), UTGD128877. 33. *O. hexagona* (Williamson 1848), UTGD128878 . 34. *O. lineata* (Williamson 1848), UTGD128879. 35. *O. melosquammosa* (McCulloch 1977), UTGD128880. 36. *O. ramulosa* (Chapman 1907), UTGD128881. 37. *O. squamosa* (Montagu 1803), UTGD128882. 38. *O. subacuticostiformis* Albani & Yassini 1989, UTGD128883. 39. *O. tasmanica* Parr 1950, UTGD128884. 40. *O.* sp. 1, UTGD128885.

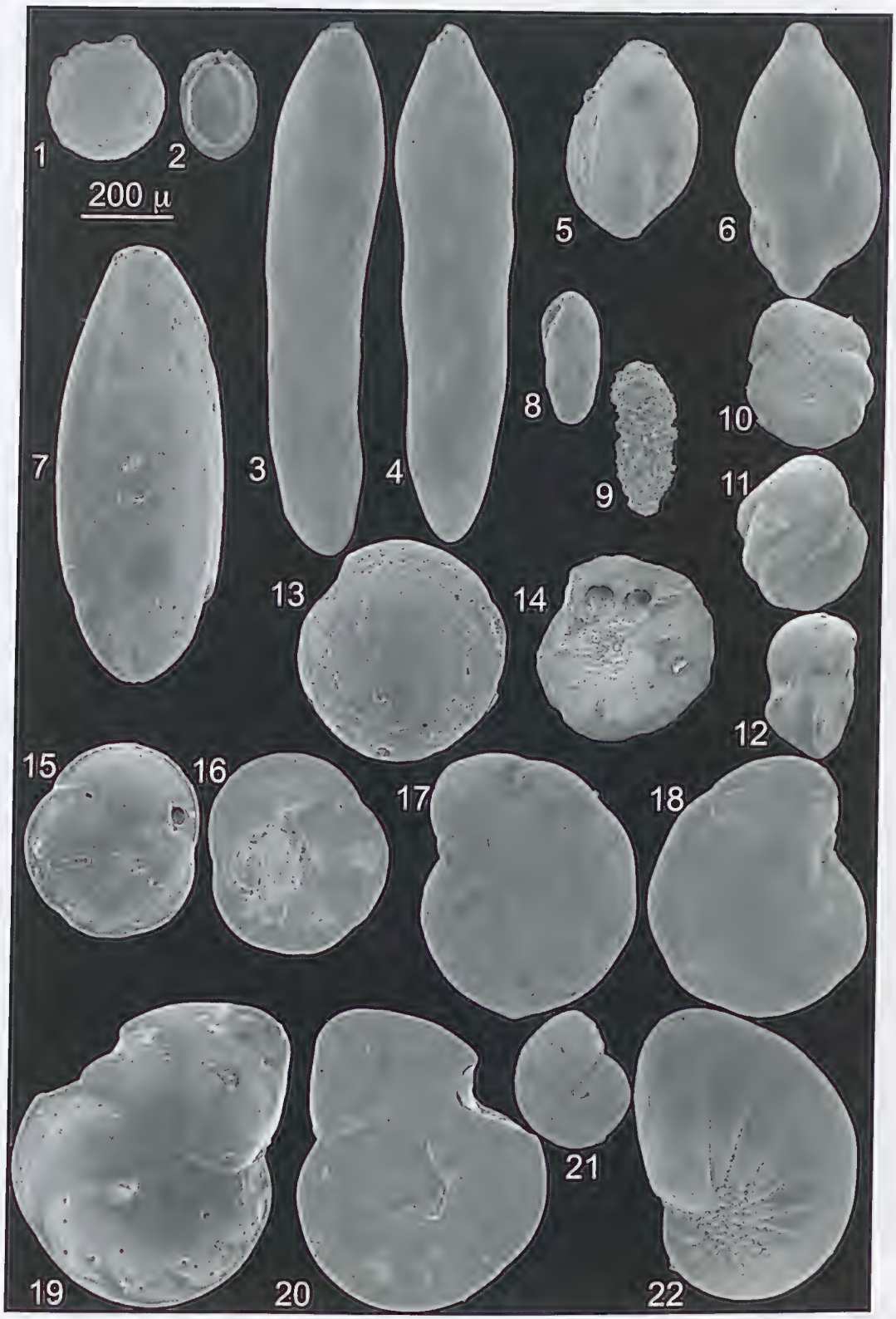


PLATE 2

Pliocene benthic Foraminifera, Flinders Island. 1. *?Oolina* sp., UTGD128886. 2. *Pseudofissurina* sp., UTGD128887. 3, 4. *gen. et sp. nov.* Quilty, 2014. Holotype, UTGD128888. 5. *Guttulina communis* (d'Orbigny 1826), UTGD128891. 6. *G. regina* (Brady, Parker & Jones 1870), UTGD128892. 7. *Sigmoidella kagaensis* Cushman & Ozawa 1928, UTGD128893. 8. *Elongobula arethusae* Revets 1993, UTGD128894. 9. *Virgulopsis* sp., UTGD128895. 10-12. *Discanomalina vermiculata* (d'Orbigny 1839), UTGD128896. 13. *Mesorotalia* sp., UTGD128897. 14. *Mesorotalia* sp., UTGD128898. 15, 16. *Discorbinella* cf *vitrevoluta* (Hornibrook 1961), UTGD128899. 17, 18. *Parredicta kalimnensis* (Parr 1939), UTGD128900. 19, 20. *Planodiscorbis* sp., UTGD128901. 21. *Astrononion novozelandicum* Cushman & Edwards 1937, UTGD128902. 22. *Pseudononion victoriensis* (Cushman 1936), UTGD128903.

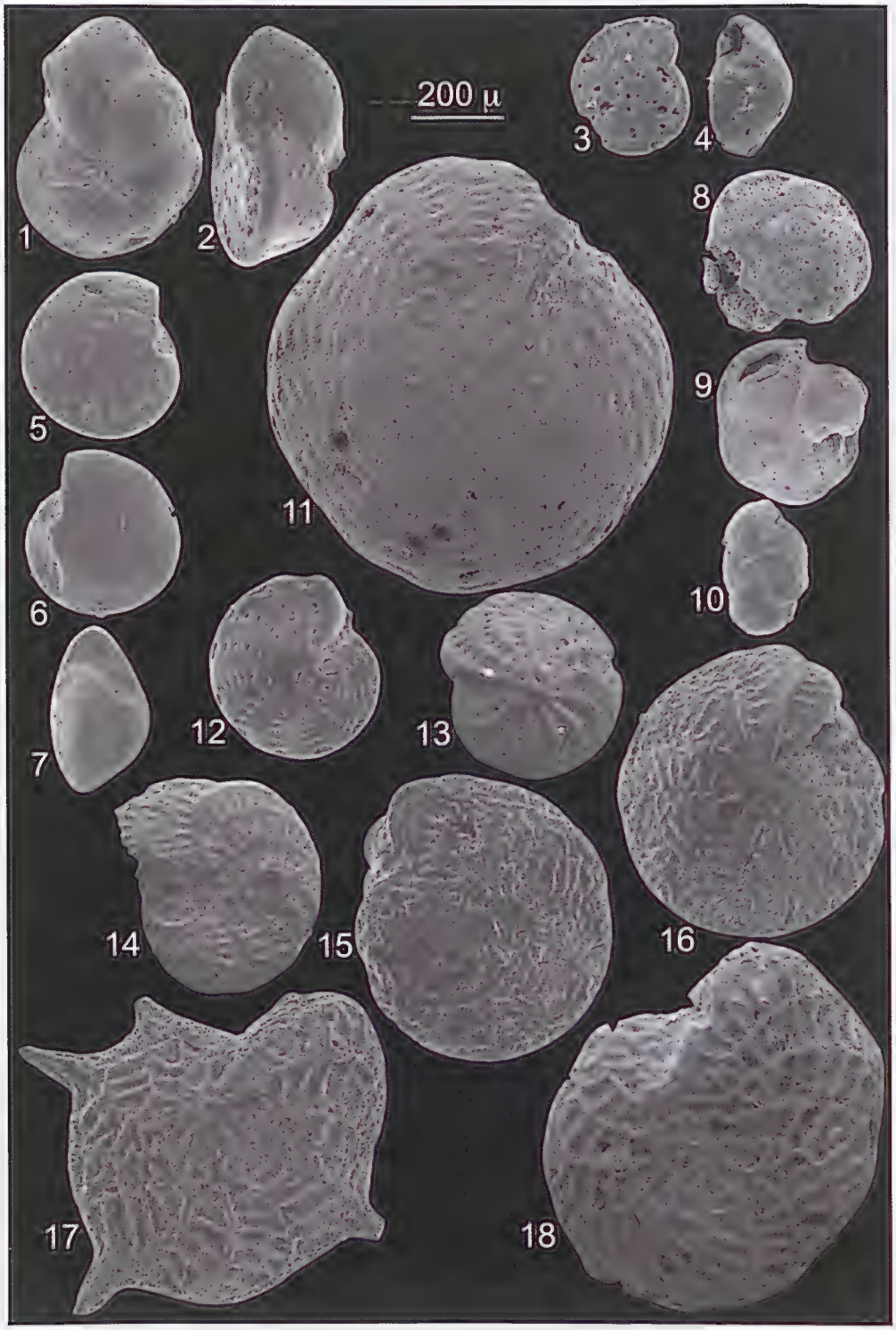


PLATE 3

Pliocene benthic Foraminifera, Flinders Island. 1, 2. *Cibicides ihungia* Finlay 1940, UTGD128904. 3, 4. *C. thiara* (Stache 1864), UTGD128905. 5-7. *C.* sp. 1, UTGD128906. 8, 9. *C.* sp. 2, UTGD128907. 10. *Dyocibicides biserialis* Cushman & Valentine 1930, UTGD128908. 11. *Elphidium craticulatum* (Fichtel & Moll 1798), UTGD128909. 12. *E. advenum advenum* (Cushman 1930), UTGD128910. 13. *E. crispum crispum* (Linné 1758), UTGD128911. 14. *E.* sp. 1, UTGD128912. 15, 16. *Notorotalia clathrata* (Brady 1884), UTGD128913. 17. *Parrellina imperatrix* (Brady 1881), UTGD128914. 18. *P. verriculata* (Brady 1881), UTGD128915.

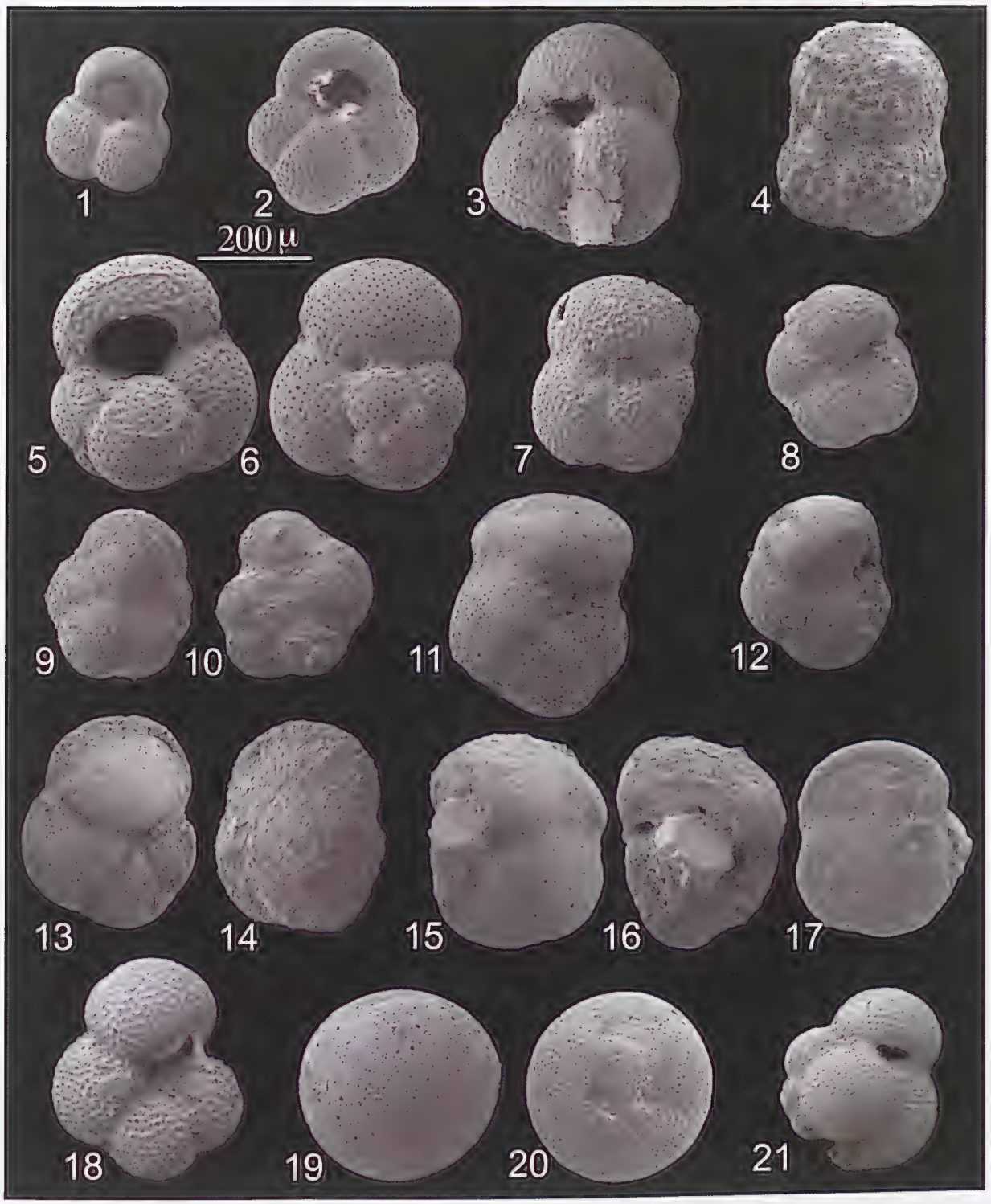


PLATE 4

Pliocene planktonic Foraminifera, Flinders Island. 1. *Globigerina apertura* Cushman 1918, UTGD128916. 2. *G. bulloides* d'Orbigny 1826, UTGD128917. 3. *G. falconensis* Blow 1959, UTGD128918 . 4. *G. woodi* Jenkins 1960, UTGD128919. 5, 6. *Globigerinoides obliquus* Bolli 1957, UTGD128920. 7. *G. quadrilobatus* (d'Orbigny 1846), UTGD12891. 8. *Neogloboquadrina pachyderma* (Ehrenberg 1861), UTGD128922. 9, 10. *N. humerosa* (Takayanagi & Saito 1962), UTGD128923. 11. *Globorotalia crassaformis* (Galloway & Wissler 1927), UTGD128924. 12. *G. puncticulata* (Deshayes 1882), UTGD128925. 13, 14. *G. pliozea* Hornibrook 1982, UTGD128926. 15-17. *G. mons* Hornibrook 1982, UTGD128927. 18. *G. 'obesa'* Bolli 1957, UTGD128928. 19. *Orbulina universa* d'Orbigny 1839, UTGD128929. 20. *O. suturalis* Brönnimann 1951, UTGD128930. 21. *Globigerinita uvula* (Ehrenberg 1861), UTGD128931.

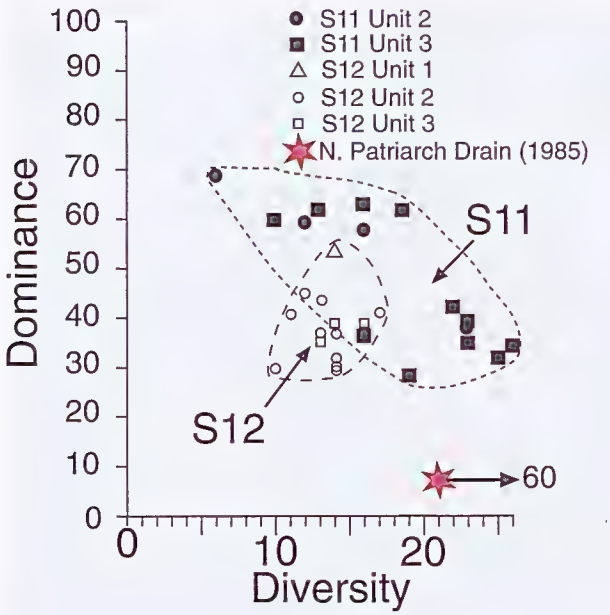


FIG. 3 — Dominance/diversity relationships between samples from sections S11 and S12. Those from North Patriarch Drain (1985) (red star) provided for comparison.

depth but quieter conditions with time, probably indicating deposition during a transgressive event (or local depression of a land surface).

Agglutinated species. Agglutinated forms occur in only two samples in trace quantities, both in S11. They appear to be virtually absent from the environments represented and are of little significance (other than absence) in interpretation of the environment at the time.

Miliolids. There is a very marked difference in the occurrence of simple miliolids between the two sections (fig. 5). In S11, species of *Quinqueloculina* and *Triloculina* occur throughout but in S12, these genera are rare and occur only in the lowest samples and then only in very low abundance. In S11, miliolids have an anitithetic relationship with *Parredicta kalimnensis* (Parr, 1939).

Bolivinids. The term is used to include the elongate, normally infaunal species. Their virtual absence supports the indications from rarity of cassidulinids, that the environment was a low nutrient one.

Cassidulinids. This group is rare and the significance lies in absence. As cassidulinids are infaunal, this may indicate a low nutrient, or more turbulent environment.

Elphidium. This genus is very diverse and a higher component in S11 (c. 7%) than in S12 (5%) but little consistent trend of change with time is evident (fig. 5). *Elphidium pseudonodosum* Cushman appears to be absent and Parr (1939) stated that it occurred only in Kalimnan strata at Hamilton in western Victoria. If present, it may be included in counts of other species such as *E. crispum*.

Parrellina. This genus is generally more abundant in S12 than in S11 (fig. 5). It has two species – *P. verriculata* and *P. imperatrix*. The difference is only in the presence or absence of prominent, robust marginal spines and it is likely that the difference is of little biological significance. *P. verriculata* dominates throughout. The genus is consistently more abundant in S12 than in S11.

Notorotalia. *Notorotalia* is generally relatively more important in S12 than in S11 (fig. 5).

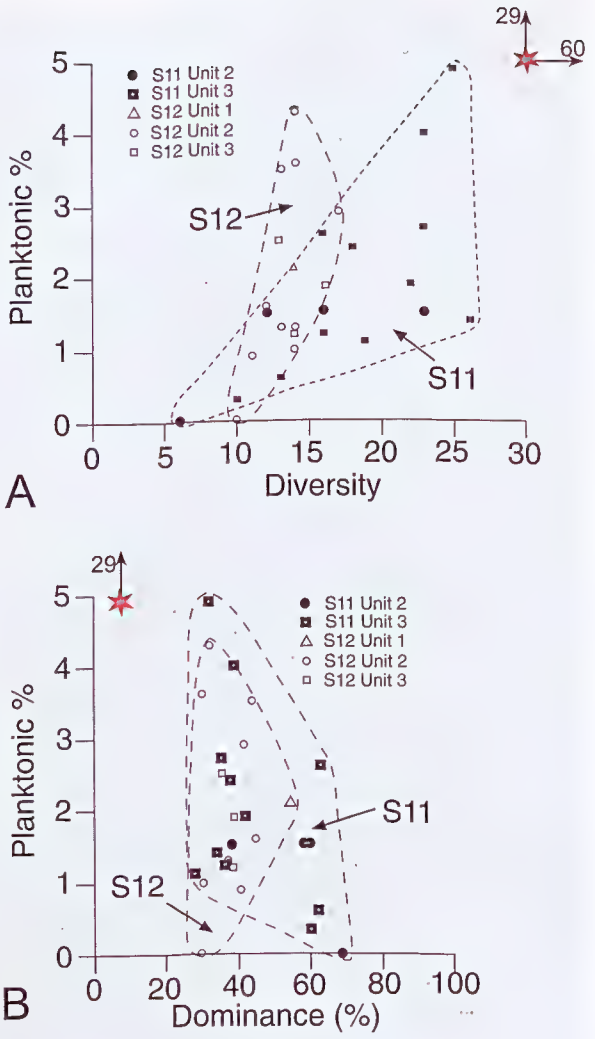


FIG. 4 — (A) Diversity vs planktonic foraminiferal content in sections S11 and S12. That from North Patriarch Drain (1985) (red star) provided for comparison. (B) Dominance vs planktonic percentage in Sections S11 and S12. That from North Patriarch Drain (1985) provided for comparison.

Parredicta kalimnensis. This genus and species, without any obvious modern equivalent, is the dominant form in all samples studied and is consistently more abundant in S11 than in S12 but there is a marked trend towards higher content in S11 with time (fig. 5).

Cibicides. Each section has a trend towards decreasing *Cibicides* content with time but the content in S12 is generally higher than in S11 (fig. 5).

Planktonic species. Planktonic forms make up only a very small proportion of samples, approximately 2% in both sections, but the diversity combined between sections is high.

CONTRASTS BETWEEN NORTH PATRIARCH DRAIN (1985) AND S11/S12

A major departure between Sections S11/12 and NPD1985 lies in the planktonic foraminiferal faunas and age implications. NPD1985 contains sinistral *Neogloboquadrina*

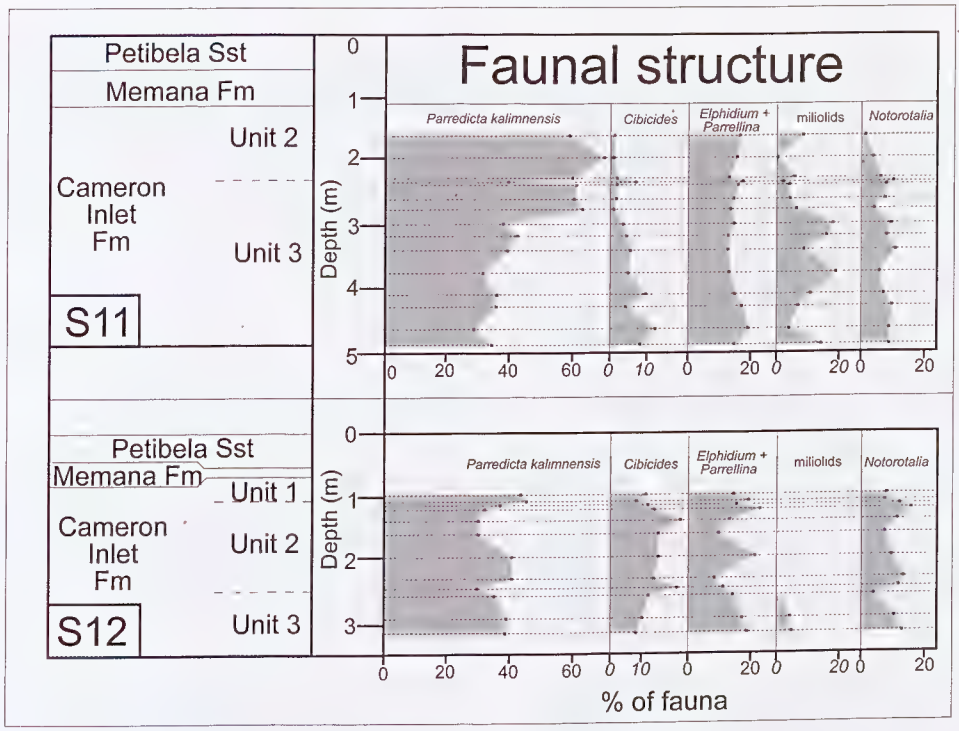


FIG. 5 — Comparison of faunal structure in sections S11 and S12.

pachyderma (Ehrenberg, 1861) that are fully developed kummerforms. *Orbulina universa* d'Orbigny, 1839 is rarer than expected compared with S11/12 samples. The sample lacks *Globigerinoides, Globorotalia mons, G. inflata* and *G. puncticulata.* It is a cool climate fauna deposited in an inner-mid-continental shelf setting and thus contains the full diversity of planktonic species, in contrast with the other sections which are shallower water samples perhaps excluding some of the species that live in a deeper water environment. The age determination for S11/S12 is discretely older than that of NPD1985 that now appears to belong to the interval 4.40–3.45 Ma. The absence of *G. mons* supports this conclusion.

Both the NPD1985 and S11/S12 sections, even if different in age within the Pliocene, are typically Kalimnan in age and fauna, partly equivalent to the Jemmys Point Formation of eastern Victoria. Parr (1939) listed those species that he took to be characteristic of the Kalimnan and both sections have faunas that clearly are Kalimnan, marked especially by the dominance of *Parredicta kalimnensis* although much more dominant (40–60%) in S11/S12 than in NPD1985 (8%). Many of these species have disjunct distributions within the southeastern Australian Neogene but the combination seems to occur only in the Kalimnan. Carter (1964) reviewed the faunas of this age from the onshore Gippsland Basin and several of the species listed by Parr (1939) were not discussed, suggesting absence from the samples he studied. This, in turn, indicates that there was some environmental differentiation at the time and that the faunas responded to these differences. NPD1985 has *F. intermedia* although extremely rare. *Nororotalia clathrata, Guttulina regina, G. seguenziana, Pseudononion victoriensis* and *Uvigerina miozea* are present in each section. *Parrellina imperatrix* and *P. verriculata* are restricted to the S11/S12 sections. *Pseudopolymorphina victoriensis* Parr, 1939 has not been identified but a new genus and species in S11 and S12 may be an analogue species in both size and abundance terms. *Ammonia beccarii* has not been seen.

NPD1985 lacks the earliest Pliocene species and also contains a mollusc fauna that Darragh (1985) referred to his Molluscan Assemblage XVII of Late Pliocene age and thus younger than his Molluscan Assemblage XVI which comes from the type Kalimnan, apparently the correlate of the S11/12 sections. The single specimen of *O. universa* recovered from NPD1985 is 0.32 mm in diameter, consistent with those from Sections S11 and S12, and indicating similar water temperature.

The implications of this age difference are that the CIF represents the entire Pliocene, and either that it consists of the products of more than one discrete depositional event, or that the sections studied are from different, as yet undifferentiated, formations.

PALAEOENVIRONMENT

Orbulina universa occurs sporadically throughout the sections and the specimens are thin-walled and very small, usually approximately only 0.35 mm (0.27–0.37 mm, all <0.40 mm). In extrapolating the results of the classic study by Bé *et al.* (1973) of *O. universa* in the Indian Ocean (fig. 6), it seems that the specimens found here lived at the lowest end of the species' temperature tolerance, probably several degrees lower than 15°C, in normal marine salinity. Water depths were very shallow (see dominance/diversity data) and thus the data of Bé *et al.* most likely to be applicable are those of their Text-figure 11 in which diameters ranged from 0.4–0.85 mm. Extrapolating the trend in that figure indicates that water temperature was approximately 12°C. The few specimens are not well enough preserved to allow study of the other features – pore density and pore diameter – examined by Bé *et al.* (1973). The interpreted temperature is several degrees cooler than in modern times.

Dominance/diversity relationships (figs 3, 4A, B) suggest that the environment at S12 was more stable than that at S11. The higher miliolid and *Elphidium* content in S11

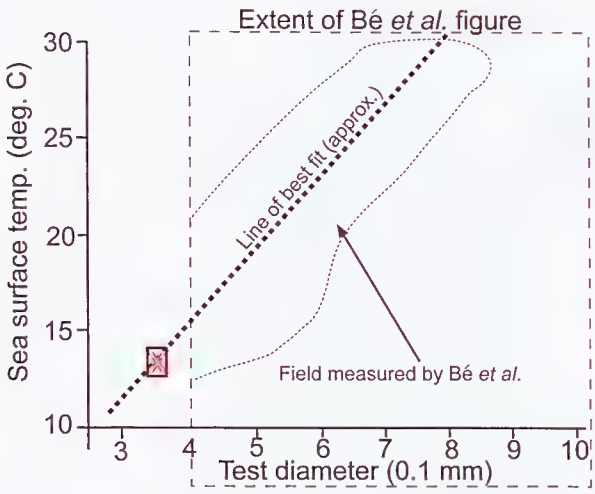


FIG. 6 — Size of Orbulina universa *from Flinders Island compared with those of Bé* et al. *(1973). X marks the Flinders Island sample.*

indicates some outer estuarine influence, and both localities were in very shallow, fully marine water. The high proportion of attached forms, (*Dyocibicides/Cibicides/Discorbinella*), more so in S12, suggests a seagrass environment well within the photic zone. The low planktonic percentage (0–3.5%, normally <2%) is consistent with this interpretation.

Section S12, while generally depauperate in miliolids, did commence with a few species but these abandoned the environment soon after deposition began suggesting a lessening of any estuarine influence and a transition to a more open or protected marine environment, consistent with generally deeper waters, in turn suggesting that deposition occurred during a transgressive phase. There is little trend in section S12.

Parredicta kalimnensis content is antithetic to attached forms but its higher abundance in S11 coincides generally with diminished miliolid abundance, indicating that it was a close inshore form, perhaps with some ability to survive outer estuarine conditions. The trends in *P. kalimnensis* seem to correlate with the implications of the ostracod data. The lower abundance in NPD1985 with its higher planktonic percentage seems to indicate that *P. kalimnensis* favoured shallower, closer inshore waters.

The presence of a significant component of poorly preserved eroded robust species amongst otherwise well-preserved delicate forms suggests that the generally quiet, shallow water environment was occasionally subject to more turbulent conditions, during storms with an easterly source. Such storm conditions allowed the wave base to be deepened.

The CIF in S11/S12 contains a diverse ostracod fauna, the majority of which have been identified previously from Recent coastal environments on southeastern Australia (Yassini & Jones 1995). The fauna comprises 39 species from a total of 24 genera and is typical of a generally shallow, consistently marine environment. Dominant species include *Malabaricythere oceanica* Yassini & Jones, 1995, *Trachyleberis ("Ponticocythereis") jervisbayensis* Yassini & Jones, 1995, *Bradleya bassbasinensis* Yassini & Jones, 1995, *Cytheropteron wrighti* Yassini & Jones, 1987, *Phlyctenophora zealandica* Brady, 1880 and *Cytherella dromedaria* Brady, 1880. The majority of species are stenohaline, but euryhaline species, common in marine environments, are also present.

The spectrum of species remained relatively constant during deposition of the Formation; however, some subtle changes in the abundance of species between samples suggest a gradual shallowing and increasing protection of the marine environment over time. The major shifts in these changes correlate loosely with the stratigraphic units of the Formation. The abundance of species typical of open marine conditions decreases from Unit 3 to Units and 1. The abundance of *P. zealandica*, a euryhaline species usually found in quiet protected coastal environments (Hartmann 1978, 1979, 1980, 1981), is greatest within Unit 1, suggesting that the unit may represent an enclosed, quiet protected shallow marine embayment or bay as implied from the lithology of the unit.

CONTRIBUTIONS TO UNDERSTANDING OF EVOLUTION OF THE PLIOCENE OF SOUTHERN AUSTRALIA

Much of the study of the later Neogene of southern Australian Foraminifera has concentrated on the Miocene and treated the Pliocene rather cursorily, even though changes in the southern Australian environment during the Pliocene have been profound, with details yet to be fully elucidated. To date, the prime source of biostratigraphic control has been on molluscs. Parr (1939) listed those forms of Foraminifera that he took to be characteristic of the Pliocene of southeastern Australia and his approach has stood the test of time. Li *et al.* (1996), in reviewing endemism in southern Australian foraminiferal faunas, could make only brief comments on the issue as it related to the Pliocene, indicating that southern Australian foraminiferal faunas were essentially modern in aspect with *Parredicta* as the genus most apt to be regarded as the endemic one. This study reinforces the view expressed by Li *et al.* (1996) because, while considerable diversity is encountered, very few new species are recorded.

Better understanding will need local biostratigraphic resolution at higher level than exists at present. The material studied here is a little unusual in that the New Zealand biostratigraphic scheme, which has been well studied, seems to be highly applicable.

Carter (1964) reviewed the foraminiferal biostratigraphy of the Gippsland Basin. The Flinders Island sections relate to the Jemmys Point and Tambo River Formations but the faunas on Flinders Island, while having many species in common with the Gippsland Basin formations, are much more diverse while still not allowing correlation on an individual formation basis with those of the Gippsland Basin. *Parredicta kalimnensis* and *Pseudononion victoriense* are characteristic of all. Carter (1964) quoted a diameter for *O. universa* of 0.59 mm, which is much larger than the Flinders Island specimens although it is clear from Carter, that specimens are as rare in his sections as in Flinders Island sections. In terms of Bé *et al.* (1973), Carter's specimens reflect a temperature closer to 20°C or even higher, indicating that northern Gippsland Basin was bathed in warmer water of the East Australian Current while farther south was subject to much cooler waters as indicated in Warne & Soutar (2012). The apparent anomaly between high sea level and cool local temperature is perhaps best explained by a scenario in which the East Australian Current (EAC) at the time flowed east (as it does now) from a position well north of Flinders Island, leaving Flinders Island bathed in cooler water.

Mallett (1982) documented the planktonic foraminiferal fauna of the Jandakot Beds in the Perth (Western Australia) area, recording a Late Pliocene age on the basis of primitive forms of *Globorotalia truncatuloides* (d'Orbigny, 1839). Examination of his figures suggests that his specimens could be compared with *G. tosaensis* Takayanagi & Saito, 1962 the immediate predecessor to *G. truncatulinoides*. He noted that it was a transitional form. The transition took place at the traditional (1.85 Ma) Pleistocene/Pliocene boundary. He estimated the temperature at the time to be comparable with the modern. He made no mention of the presence/absence of *O. universa*.

James *et al.* (2006) studied the Late Pliocene Roe Calcarenite of the Eucla Basin and recorded an age of 2.0–3.4 Ma. The age was not given in terms of either the Blow (1969) or Hornibrook *et al.* (1989) biostratigraphic schemes based on planktonic organisms. The environment of deposition of that unit was considerably warmer than at present as judged by the presence of abundance of tropical [mollusc] taxa. The Roe Calcarenite, like the CIF, is thin, very shallow water and characterised by very diverse mollusc fauna suggesting that it represents the peak incursion of the sea at the time. Deposition of the Roe Calcarenite perhaps equates with Haq *et al.'s* (1987) Cycle 3.6, in contrast to the CIF which may equate to Cycle 3.4.

It has long been recognised that a major unconformity exists between the well-studied Miocene sections in southeastern Australia and the Pliocene, and its extent and possible origin were reviewed and discussed in detail by Dickinson *et al.* (2002). It includes largely the time span of the Mitchellian and Cheltenhamian Australian stages (Wilkins 1963). The Miocene strata have been folded and faulted in places and eroded to various levels and overlain by the earliest Pliocene such as the Grange Burn Formation and Whalers Bluff Formations (Otway Basin), Brighton Group (Torquay sub-basin and Port Phillip Basin) and Haunted Hill Fomation (non-marine) or Jemmys Point Formation (Gippsland Basin). The Grange Burn Formation in the Hamilton area has been dated by Sr techniques to 5–4.0 Ma (Dickinson *et al.* (2002), an exact equivalent to the material studied here. The Moorabool Viaduct Formation has yielded an Sr based age of 4.5 Ma. Dickinson *et al.* (2002) noted that, in the Torquay sub-basin, folding continued into the Pliocene sedimentary section. In the Gippsland Basin, erosion of the folded Miocene sequence was Late Miocene-Early Pliocene (8–4 Ma; Dickinson *et al.* 2002) and the Jemmys Point Formation is younger, correlating with N20 planktonic foraminiferal zone. Holdgate *et al.* (2003) postulated that folding in the Gippsland Basin continued until approximately 1 Ma.

The Whalers Bluff Formation of southern Victoria has been the subject of considerable research (Singleton *et al.* 1976, Warne & Soutar 2012) and the history correlates closely with that on Flinders Island. Warne & Soutar (2012) showed that it was formed by two depositional events – one of Kalimnan/Zanclean age recorded at one metre, overlain disconformably at 5 m by one dated as Late Pliocene/Piacenzian, the boundary between the two units being placed at 3.81 m. This appears to be the same sequence, timing and sea level highstand history as is represented on Flinders Island.

CONCLUSIONS

The presence of *in situ*, articulated Pliocene molluscs enabled identification of the Cameron Inlet Formation over ~10 km² of previously unmapped outcrop. This is the northwesternmost extent of the CIF of fossiliferous marl, sand and silt. Here the formation is higher in altitude (23–32 m) than elsewhere (4–19 m). The southern extent of the CIF on Flinders Island was constrained topographically to a lower elevation (4–19 m) and blocked by Early Miocene basalt which is now largely eroded to a similar elevation as the surrounding coastal plain (Sutherland & Kershaw 1971). *In situ* weathered granitic soils also occur near the southern limit of the CIF (fig. 1C) indicating that granitic outcrops may also have created a physical barrier to Pliocene marine deposition in the area.

Foraminifera and ostracods from new sections S11/S12 of the CIF are very Early Pliocene in age and represent an age not previously recorded on Flinders Island. The sections are characterised by benthic foraminiferal faunas that are typically Kalimnan in southeastern Australian stage terms. The molluscan fauna from this section has not been studied to date. The sections can be correlated by planktonic Foraminifera with a very narrow interval at DSDP Site 284 (central Tasman Sea), particularly Cores 14 and 15 that lie on the Kapitean/Opoitian boundary, very early Pliocene in New Zealand terms. The fauna relates to a narrow interval in the older half of the Opoitian, early to mid-N19 in international planktonic foraminiferal zone terms, approximately 5.3–4.4.Ma, or early to mid-Zanclean in European nomenclature. This age correlates closely with Haq *et al.'s* (1987) Eustatic Cycle 3.4 of Supercycle TB3, the major onlap and close to the highest sea level of the last 10 million years (Miller *et al.* 2005).

The fauna is distinctly older than that recorded by Quilty (1985) from supposed CIF from North Patriarch Drain that is Late Pliocene but still Kalimnan in aspect. The Kalimnan therefore may represent the entire Pliocene (5.3–2.6 Ma). It is then possible that the Kalimnan may be divisible into early (characterised by Darragh's 1985 Mollusc Assemblage XVI) and late (characterised by Darragh's 1985 Mollusc Assemblage XVII) substages, both within the Pliocene. Probable correlation of the various faunas is depicted on figure 7.

The implications of this age difference are either that the CIF consists of the products of more than one discrete depositional event, or that the sections studied are from different, as yet undifferentiated, Kalimnan formations.

The Dutchman Coquinoid Limestone may best be considered a facies variant or member of the CIF rather than a formation in its own right.

The Pliocene sediments on Flinders Island correlate very closely with the history recorded in the Whalers Bluff Formation of southern Victoria that also consists of the products of two depositional events, contemporaneous with those on Flinders Island.

Deposition occurred in marine waters less than 20 m deep in sea surface temperatures cooler than today, perhaps some 12–13°C.

The sections on Flinders Island can be regarded as the southwesternmost onshore margin of the marine Cenozoic of the Gippsland Basin

Precise correlation of southeastern Australian stages with international zonal schemes is, as yet, not possible but the very Early Pliocene determination for the S11/S12 sections

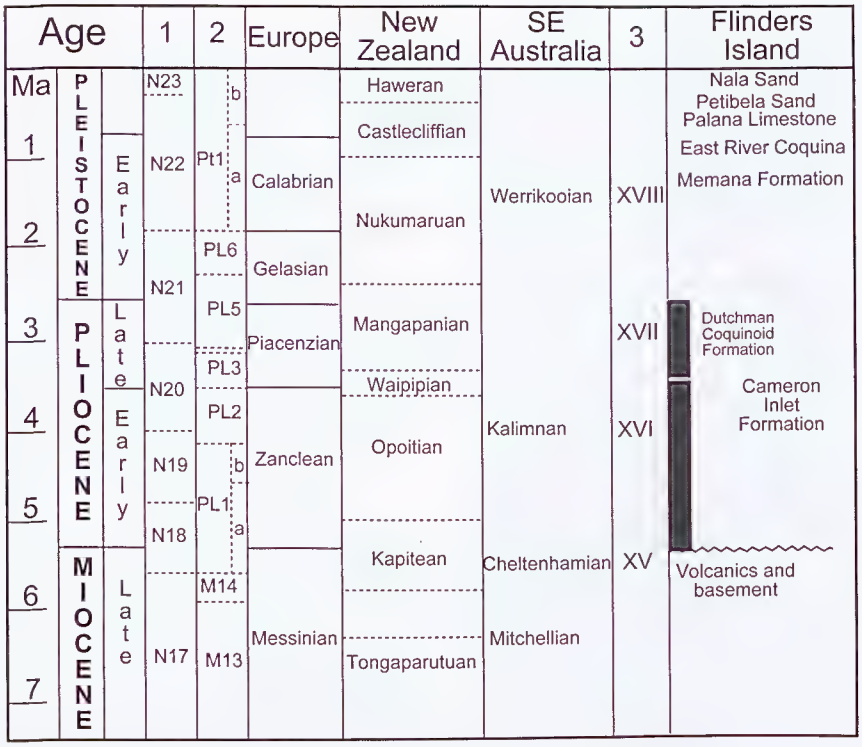


FIG.7 — Stratigraphy of Flinders Island Pliocene and younger, placed in southeastern Australian, New Zealand and European stage terms. 1, Blow (1969) planktonic foraminiferal zones. 2, Planktonic foraminiferal zones for Atlantic Ocean from Berggren et al. *(1995). 3, Mollusc Assemblages of Darragh (1985).*

helps tie this sequence to the New Zealand sequence and, via that, to the international schemes.

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APPENDIX 1. SYSTEMATIC PALAEONTOLOGY

Species allocated to the genera *Elphidium* and *Parrellina* have been identified, where possible, using the taxonomy employed by Hayward *et al.* (1997).

Unilocular species. There have been many attempts in recent decades to develop a classification that make sense of the extreme diversity of unilocular forms. Most criteria depend on minor variation on gross shape or "ornamentation" but few schemes seem to be based on any concept of genetic limits. One element in this argument is the role of details of the pattern on the neck – spiral, with horizontal striae, a bare neck or flared apertural margin. Here, a conservative approach recognises few genera.

The faunas are rich in unilocular forms and the identity and synonymy of many is confused. It is the "lumpers" vs "splitters" argument. For example, in *Lagena* some species are interpreted very broadly, others narrowly. Yassini & Jones (1995) discussed and illustrated many "species" that in other works would be taken as one. Their figures 309–316, while taken as four species, in other concepts could all be taken as variants of *L. sulcata.* The approach taken here is to compare forms with published figures, whatever the approach of the authors but to accept a limited number of genera.

Fissurina and related genera are present in many samples but usually as one or two specimens of a bewildering array of possible names even for the one form. Many species occur in very few samples. Identification is based on comparison with forms recorded in the synonymy.

The category of unidentifiable species consists dominantly of fragments of robust species, commonly eroded and rounded, and indicates that the environment at some stage was highly turbulent, apparently in conflict with the evidence of good preservation of many otherwise delicate species. It may suggest some re-cycling from earlier units, althoughy none are known.

The supraordinal classification of Foraminifera has been in a state of flux over recent decades but that below class has been comparatively settled. For this study, I use the hierarchy summarised by Hayward *et al.* (2012) but use the termination *–acea* for superfamily. While all species listed on appendix table 1 are included below, remarks are given for very few. The synonymy is not exhaustive but intended to outline the taxonomy employed with the original description, some Australian references from nearby sites, particularly Quilty (1974, 1977, 1982), and Li & McGowran (2000) as the authority.

An asterix indicates that the species is figured on the plates.

PHYLUM FORAMINIFERA d'Orbigny, 1826
CLASS ATHALAMEA Haeckel, 1862
ORDER LITUOLIDA Lankester, 1885
Superfamily VERNEUILINACEA Cushman, 1911
Family VERNEUILINIDAE Cushman, 1911

***Gaudryina convexa* (Karrer, 1865)**

Textilaria convexa Karrer 1865, 78, pl. 16, fig. 8.

Gaudryina convexa (Karrer): Burdett *et al.* 1963, 513–530; Quilty 1974, 39, pl. 1 figs 14, 15; Li & McGowran 2000, 53, figs 24S, U, V.

Remarks: A single poorly preserved specimen in NPD1985. It is not recorded from Sections 11 or 12.

ORDER TEXTULARIIDA Lankester, 1885
Superfamily TEXTULARIACEA Ehrenberg, 1838
Family TEXTULARIIDAE Ehrenberg, 1838

***Siphotextularia saulcyana* (d'Orbigny, 1839)**

Textularia saulcyana d'Orbigny 1839, 146, pl. 1, figs 21, 22.

Siphotextularia saulcyana (d'Orbigny, 1839); Li & McGowran 2000, 50, figs 24I, J.

***Siphotextularia* cf *saulcyana* (d'Orbigny, 1839)**

cf. *Siphotextularia saulcyana* (d'Orbigny): Li & McGowran 2000, 50, fig. 241J.

Remarks: A fragment of the juvenile end of a specimen. Apertural details not visible.

***Textularia candeiana* d'Orbigny, 1839**

Textularia candeiana d'Orbigny 1839, 143, pl. 1, figs 25-27; Hayward *et al.* 1999, 90, pl. 2, figs 24-26.

Textularia conica d'Orbigny: Yassini & Jones 1995, 75, figs 101, 109.

ORDER MILIOLIDA Lankester, 1885
Superfamily HEMIGORDIOPSACEA Nikitina, 1969
Family HEMIGORDIOPSIDAE Nikitina, 1969

*** *Gordiospira* sp.** **Pl. 1, fig. 1**

?*Quinqueloculina culebriana* McCulloch, 1977: Yassini & Jones 1995, 83, fig. 193.

Remarks: Initially taken to be *Quinqueloculina,* the specimen appears to be a single post-prolocular chamber. Coiling is a little oblique and thus not in one plane. Yassini & Jones illustrated a specimen that seems identical to the specimen figured here. Chamber boundaries are invisible suggesting they do not exist. This species seems to be an analogue of the Late Palaeozoic *Agathammina.*

Superfamily MILIOLACEA Ehrenberg, 1839
Family HAUERINIDAE Schwager, 1876

***Adelosina* sp.**

Remarks: A compressed quinqueloculine form with regular angular periphery and slightly extended neck, narrow aperture and single plate-like tooth. It is akin to *A. bicornis* but has a more angular periphery.

***Flintina intermedia* (Howchin, 1889)**

Hauerina intermedia Howchin 1889, 4, pl. 1, figs 6a,b.

Flintina intermedia (Howchin, 1889); Parr 1939, 70, figs 24a, b; Carter 1964, 63, pl. 1, figs 18, 19.

Remarks: This species was taken by Parr (1939) as a foraminiferal index for the Kalimnan on southeastern Australia. It is known here as a single specimen from NPD1985.

***Miliolinella subrotundum* (Montagu, 1803)**

Vermiculum subrotundum Montagu 1803, 521.

Miliolinella subrotunda (Montagu): Yassini & Jones 1995, 88, figs 1984, 195

Miliolinella subrotundata (Montagu): Hayward *et al.* 1999, 96, pl. 3, fig. 24.

Remarks: The few specimens are poorly preserved, partly through diagenesis and partly through breakage.

***Pseudoflintina crassatina* (Brady, 1884)**

Miliolina crassatina Brady 1884, 16, pl. 8, figs 5a, b.

Pseudoflintina crassatina (Brady, 1884). Yassini & Jones 1995, 86, fig. 213.

***Pyrgo* spp.**

Remarks: *Pyrgo* occurs rarely throughout the sections. All are characterised by a marked expanded chamber on one side and by T-shaped teeth, in contrast to most species of this type. One (*P.* sp. 1) has a thick adapical spine.

***Pyrgo* sp. 1**

Remarks: A single inflated specimen with thick, marked adapical spine and slightly angular periphery.

****Quinqueloculina asperula* Seguenza, 1862** **Pl. 1, fig. 2**

Quinqueloculina asperula Seguenza 1862, 120, pl. 2, figs 6-6b.

Remarks: While grossly similar to *Q. anguina arenata* Said, 1949 (Yassini & Jones 1995, 83, figs. 180–182), it lacks an extended neck and this also distinguishes it from *Siphonaperta.*

***Quinqueloculina lamarckiana* d'Orbigny, 1839**

Quinqueloculina lamarckiana d'Orbigny, 1839, 189, pl. 11, figs 14, 15: Yassini & Jones, 1995, 84, figs 203–205, 208.

***Quinqueloculina oblonga* (Montagu, 1803)** **Pl. 1, fig. 3**

Vermiculum oblongum Montagu 1803, 179, pl.10, figs 15-17.

Triloculina oblonga (Montagu): Yassini & Jones, 1995, 92, figs 188–192, 196, 197. *Quinqueloculina oblonga* (Montagu): Hayward *et al.* 1999, 102, pl. 4, figs 27, 28. *Quinqueloculina* sp. 6: Haig, 1997, figs 4, 14, 15.

Remarks: A survey of the synonymy of this form shows that it is variously placed in *Triloculina, Quinqueloculina* or *Miliolinella*, perhaps depending on the ability of the aperture to reveal its features. Specimens examined in detail have a quinqueloculine tooth. Here, Hayward *et al.* (1999) are followed even though some specimens could legitimately be placed in *Miliolinella.*

***Quinqueloculina seminulum* (Linné, 1758)** **Pl. 1, fig. 4**

Serpula seminulum Linné 1758, 786.

Quinqueloculina seminulum (Linné): Quilty 1974, 52, pl. 2, figs 52, 53; Yassini & Jones, 1995, 85, figs 198, 199; Hayward *et al.* 1999, 103, pl. 5, figs 9, 10.

Remarks: The most widespread of the miliolids. Several specimens have walls that are pitted.

***?Quinqueloculina poeyana victoriensis* Collins, 1974** **Pl. 1, fig. 5**

?*Quinqueloculina poeyana victoriensis* Collins 1974, 16, pl. 1, figs 6, b.

Remarks: The identification is tentative as the characteristic apertural details are not preserved. Collins (*op. cit.*) noted that the form he described has been found in older sediments of Victoria.

***Quinqueloculina* sp. A**

Remarks: This form occurs in the NPD1985 and appears to have apertures at each extremity. The most similar form appears to be *Quinqueloculina quinquecarinata* Collins, 1958, which has striae or narrow costae particularly along early chambers.

***Siphonaperta ammophila* (Parr, 1932)**

Quinqueloculina ammophila Parr 1932, 8, pl. 1, fig. 10.

Siphonaperta ammophila (Parr, 1932). Ludbrook, 1961, 71, pl. 6, fig. 2; Quilty 1974, 56, pl. 2, figs 67, 68.

***Triloculina earlandi* Cushman, 1954**

Triloculina earlandi Cushman *et al.* 1954, 338, pl. 85, fig. 3.

Remarks: Specimens of this form commonly are poorly preserved but integrating of the characters supports the identification.

***Triloculina gilboei* Beck, 1943**

Triloculina gilboei Beck 1943, 594, pl. 101, figs 1–3: Li & McGowran 2000, 55, fig. 22S.

Remarks: This species occurs uniformly with *T. trigonula* and may be an extreme variant.

***Triloculina laevigata* d'Orbigny, 1826**

Triloculina laevigata d'Orbigny 1826, 134 (figures Terquem 1878, 57, pl. 5, figs 20, 21); Quilty 1974, 58, pl. 2, figs 76, 77.

Remarks: Three names could be used for this species and I have chosen d'Orbigny's. Other names are *T. laevigata* but attributed to Terquem, or *T. inflata* d'Orbigny, 1826. It seems all are available and for the same species.

***Triloculina tricarinata* d'Orbigny, 1826**

Triloculina tricarinata d'Orbigny 1826, 299, modeles no 94: Hayward *et al.* 1999, 106, pl. 5, figs 29, 30.

Remarks: Most specimens, while clearly distinct from *T. trigonula* by virtue of sharper periphery to all chambers, are not as sharp as in many identifications and it almost intergrades with *T. trigonula.*

***Triloculina trigonula* (Lamarck, 1804)** **Pl. 1, fig. 6**

Miliolites trigonula Lamarck 1804, 351, pl. 17, figs 4a-c.

Triloculina trigonula (Lamarck): Quilty 1974, 59, pl. 2, figs 80, 81; Li & McGowran 2000, 55, fig. 25T; Hayward *et al.* 1999, 106, pl. 5, figs 31, 32.

Remarks: Occurs almost routinely with *T. tricarinata* but always is very dominant.

Family SPIROLOCULINIDAE Wiesner, 1920

***Spiroloculina canaliculata* d'Orbigny, 1846**

Spiroloculina canaliculata d'Orbigny 1946, 269, pl. 16, figs 10-12: Li & McGowran 2000, 56, fig. 25L.

ORDER LAGENIDA Lankester, 1885
Superfamily NODOSARIACEA Ehrenberg. 1838
Family NODOSARIIDAE Ehrenberg. 1838

***Dentalina godjeni* Quilty, 1969**

Dentalina godjeni Quilty 1969, 97, fig. 2; Quilty, 1974, 63, pl. 3, fig. 91.

Remarks: The test is generally smooth and lacks any basal spine. The only 'ornament' is weakly developed longitudinal costae in the final intercameral sutures and/or a few weak surface ribs on the early chambers. Intercameral sutures flush or weakly depressed.

Dentalina subemaciata Parr, 1950

Dentalina subemaciata Parr 1950, 329, pl. 12, fig. 1; Jones 1994, 74, pl. 62, figs 25, 26.

Remarks: A large smooth form over 2 mm long but incomplete.

Dentalina spp. indet.

A few unidentifiable fragments in three samples.

***Frondicularia* juv. sp. indet.**

Remarks: The juvenile of a palmate species lacking a basal spine. It consists of the spherical proloculus and a single frondicularine chamber with a few weakly developed ribs at the base.

Family VAGINULINIDAE Reuss, 1860

***Lagena flatulenta* Loeblich & Tappan, 1953** **Pl. 1, fig. 7**

Lagena flatulenta Loeblich & Tappan 1953, 60, pl. 11, fig. 10; Yassini & Jones 1995, 104, fig. 302.

Remarks: The simplest of forms consisting of a spherical smooth body with simple tubular neck and open aperture. It may be the form recorded by Jones (1994, pl. 56, fig. 14) as *Lagena* sp. nov.

***Lagena perlucida* (Montagu, 1803)** **Pl. 1, fig. 8**

Vermiculum perlucida Montagu 1803, 525, pl. 14, fig. 3

Lagena perlucida (Montagu, 1803). Cushman 1923, 46, pl. 8, figs 12, 13; Li & McGowran 2000, 73, fig. 31A

Remarks: Differs from that illustrated by Li & McGowran in having a spiral neck. The costae extend from the base to the apertural end but do not meet at the flat base.

***Lagena striata paucistriata* Yassini & Jones, 1995** **Pl. 1, fig. 9**

Lagena striata paucistriata Yassini & Jones 1995, 106, figs 323–325.

Remarks: This form consists of a simple spherical body with clearly differentiated tubular neck with simple aperture; short basal spine. Surface marked by weakly developed costae.

***Lagena striatospiralata* Albani & Yassini, 1989** **Pl. 1, fig. 10**

Lagena striatospiralata Albani & Yassini 1989, 380, figs 2x, y; Yassini & Jones 1995, 107, figs 314, 315.

Remarks: A simple form with spherical body and well differentiated, long narrow neck with spiral pattern. Surface with numerous fine costae extending from apical end to base. The species has much in common with *L. sulcata* (Walker & Jacob, 1798) and is differentiated on the basis of the multitude of costae and a spiral neck.

***Lagena sulcata* (Walker & Jacob, 1798)** **Pl. 1, fig. 11**

Serpula (*Lagena*) *sulcata* Walker & Jacob 1798, 634, pl. 14, fig. 5.

Lagena sulcata (Walker & Jacob): Quilty 1974, 69, pl. 3, fig. 106; Jones 1994, 64, pl. 57, figs 23, 25-27, 33, 34; Li & McGowran 2000, 74, fig. 30W.

Remarks: This is a classic case of "splitters" vs "lumpers" but I have followed Jones (1994) in treating this group of intergradational forms as one species. An abundant form. There does seem to be a differentiation of forms with much more abundant, finer striae that are here placed in *L. striatospiralata.*

***Lagena* sp. 1** **Pl. 1, fig. 12**

Remarks: Elongate, broadest approximately 1/3 of length from base

with tapering neck. Surface with 5 narrow, low punctate costae from base, where they join, to the neck. A single specimen in NPD1985. The most similar species appears to be *L. quinquelaterata* Brady, 1881, as figured by Jones (1994, p. 72, pl. 61, figs 15, 16) but *L.* sp. 1 is relatively shorter, has punctae along each costa and lacks a basal spine.

***Lagena* sp. 2** **Pl. 1, fig. 13**

Remarks: A slightly elongate species characterised by dominantly smooth ovoid body tapering gently to neck with single raised ring and flared simple aperture. Lower test with about six radiating short costae that do not join at the base. Haynes (1973) described a similar but more elongate form as *L. doveyensis* but it has an unadorned neck and more costae (he termed them striae) at the base. *L. doveyensis* is only questionably differentiated from *L. semistriata* (Williamson, 1848) (see Jones 1994, pl. 57, figs 13, 14).

***Lagena* sp. 3** **Pl. 1, fig. 14**

Remarks: It is not certain that this is a foraminiferid but body shape and apparent apertural end suggest it is. The surface is marked by very many irregularly circular "outgrowths" with roughened flat tops and deep clefts between.

***?Lagena* sp.** **Pl. 1, fig. 15**

Remarks: Two specimens in NPD1985. Unilocular, spherical, with finely irregular polygonal surface pattern. It has no neck and the aperture is a simple hole. It is unclear whether or not it is a foraminiferid but it is very similar to many lagenids but lacks a neck. This form is akin to *O. favosopunctata* (Brady, 1881) as figured by Jones (1994, pl. 58, fig. 35) but broken or without a neck.

***Lenticulina foliata* (Stache, 1864)**

Robulina foliata Stache 1864, 245, pl. 23, fig. 24.

Lenticulina foliata (Stache): Li & McGowran 2000, 61, figs 28H, I.

Remarks: The identification is based on general features as the details of the aperture are not clear.

***Palmula longiformis* Bermudez, 1949**

Palmula longiformis Bermudez 1949, 158, pl. 10, figs 14, 15.

***Procerolagena clavata* (d'Orbigny, 1846)** **Pl. 1, fig. 16**

Oolina clavata d'Orbigny 1846, 24, pl. 1, figs 2, 3

Procerolagena clavata (d'Orbigny, 1846). Jones 1994, 62, pl. 56, figs 8, 9.

***Vaginulina vertebralis* Parr, 1932**

Vaginulina vertebralis Parr 1932, 221, pl. 22, fig. 42; Hayward *et al.* 1999, 115, pl. 6, fig. 24.

Family ELLIPSOLAGENIDAE A. Silvestri, 1923

***Cushmanina spiralis* (Brady, 1884)** **Pl. 1, fig. 17**

Lagena spiralis Brady 1884, 468, pl. 114, fig. 9; Loeblich & Tappan 1994, 78, pl. 139, figs 3–9.

Cushmanina tasmaniae (Quilty, 1974): Li & McGowran 2000, 75, fig. 31E.

Remarks: This is the species recorded by Li & McGowran (2000) but has a more elongate body than the holotype of *C. tasmaniae.* The form figured is less regular in growth than other specimens figured to date. The ribs on this species and the specimens figured by Loeblich & Tappan (1994) are robust and lack the perforations obvious on the figures of *Cushmanina* by Quilty (1974), Jones (1994) and Li & McGowran (2000).

***Fissurina lucida* (Williamson, 1848)** **Pl. 1, figs 18, 19**

Fissurina marginata (Montagu) var. *lucida* Williamson 1848, 17, pl. 2, fig. 7

Fissurina lucida (Williamson, 1848); Loeblich & Tappan 1994, 90, pl. 156, figs 1–3; Hayward *et al.* 1999, 119, pl. 7, figs 20, 21.

Fissurina annectens (Burrows & Holland, 1895). Li & McGowran 2000, 79, fig. 32F.

Remarks: This is the form illustrated by Li & McGowran (2000) as *F. annectens* (Burrow & Holland, 1895) but it differs from *F. annectens* in lacking a basal spine and also a narrow fissure around the lower part of the test. The test surface lacks ornamentation of any kind. The forms recorded here vary from inflated (as illustrated by Hayward *et al., op cit.*) to less so.

***Fissurina marginata* (Montagu, 1803)** **Pl. 1, figs 20, 21**

Vermiculum marginatum Montagu 1803, p. 524

Fissurina crassiannulata Collins, 1974; Li & McGowran 2000, 80, figs 32B, C.

Fissurina marginata (Montagu, 1803); Hayward *et al.* 1999, 119, pl. 7, figs 22, 23.

Remarks: This is the form illustrated by Li & McGowran (2000) as *F. crassiannulata* but the form discussed by Li & McGowran and recorded here lacks the characteristic thick solid keel, which is almost as thick as the main body of the test in Collins' species. Li & McGowran (2000) figured a species as *F. marginata* but their specimen has a clear flange developed around the base of the test and is not the species recorded here.

***Fissurina pacifica* Parr, 1950** **Pl. 1, figs 22, 23**

Fissurina pacifica Parr 1950, 314, pl. 9, fig. 10a, b; Collins 1974, 27; Jones 1994, 69, pl. 60, fig. 8.

Remarks: A slightly elongate form with smooth surface; marked by two keels on either side of a prominent punctate zone around the entire chamber, but not joining at the base. Neck short and broadening near the chamber. Two specimens were recovered from the NPD1985 originally included by Quilty (1985) in *Fissurina* spp. It was described originally from modern sediments of nearby Bass Strait.

***Fissurina* sp.** **1 Pl. 1, figs 24, 25**

Remarks: This species is characterised by an almost circular test with clearly defined groove immediately in from the margin around the body but absent from just below the aperture which is very slightly extended. In profile, the test is only slightly inflated and there is a single clear simple keel separated from the rest of the test by the groove. Surface of test smooth. Li & McGowran (2000) figured a very similar form as *Fissurina* cf. *densifasciataformis* Albani & Yassini, 1989. The form recorded here has a slightly less pronounced neck with aperture, and the marginal groove is complete around the base of the test.

***Fissurina* sp. 2** **Pl. 1, figs 26, 27**

Remarks: A single specimen in NPD. A simple form with smooth circular, slightly compressed chamber, and well-developed neck, distinctly flared at the aperture. It is very similar to species illustrated by Jones (1994, pl. 59, fig. 1) as *Fissurina seguenziana* (Fornasini, 1886) but lacks the distinct keel of that species.

***Fissurina* sp. 3** **Pl. 1, figs 28, 29**

Remarks: A single, well-preserved, unidentifiable specimen of a small, inflated, robust-ribbed species. Body highly inflated, with strong keel around most of test but weakening towards aperture. Body with two strong ribs on each side; ribs converge adapically but die out about 2/3 of way towards apical end of test leaving a ribless apical part. Centre of body with raised triangular platform that also converges on ribs.

***Fissurina* sp. 4** **Pl. 1, fig. 30**

Remarks: A simple almost circular, compressed form, lacking keel or any 'ornament' and with a hint of an adapical spine.

***Oolina emaciata* (Reuss, 1862)** **Pl. 1, fig. 31**

Lagena emaciata Reuss 1862, 319, pl. 1, fig. 9.

Oolina emaciata (Reuss): Li & McGowran 2000, 77, fig. 31T.

Remarks: This is a simple, slightly asymmetrical, smooth tear-shaped species.

***Oolina globosa* (Montagu, 1803)** **Pl. 1, fig. 32**

Vermiculum globosum Montagu 1803, 523.

Oolina globosa (Montagu): Quilty 1974, 92, pl. 4, fig. 158; Li & McGowran 2000, 77, fig. 31U.

Remarks: Various authors have recorded this seemingly simple species as *Lagena.* Yassini & Jones (1995) interpreted it to include more elongate forms such as illustrated on their Figs 369, 370 and that practice is followed here. Elongate forms are rare.

***Oolina hexagona* (Williamson, 1848)** **Pl. 1, fig. 33**

Entosolenia squamosa var. *hexagona* Williamson 1848, 20, pl. 2, fig. 23.

Lagena hexagona (Williamson): Howchin 1889, 8; Quilty 1974, 66, pl. 3, fig. 98; Jones 1994, 66, pl. 58, fig. 33; Li & McGowran 2000, 75, figs 31K, L.

Remarks: This species contains two populations, one of coarse and one of fine hexagons, the latter perhaps comparable with *F. digitale* (Heron-Allen & Earland, 1932). Li & McGowran (2000), while not commenting on this feature, did illustrate both forms. The figured specimen agrees with the form figured by Jones.

***Oolina lineata* (Williamson, 1848)** **Pl. 1, fig. 34**

Entosolenia lineata Williamson 1848, 18, pl. 2, fig. 18; Jones 1994, 63, pl. 57, fig. 13

Oolina lineata (Williamson, 1848); Albani & Yassini 1989, 387, figs 4C, D

Remarks: A common species. Modern interpretation of this species may be of a form a little more globular than Willamson's concept which is distinctly elongate.

***Oolina melosquammosa* (McCulloch, 1977)** **Pl 1, fig. 35**

Oolina melosquammosa McCulloch 1977, 82, pl. 54, figs 26-28.

Favulina melosquammosa (McCulloch, 1977); Loeblich & Tappan 1994, 86, pl. 151, figs 13–17.

***Oolina ramulosa* (Chapman, 1907)** **Pl. 1, fig. 36**

Lagena acuticosta Reuss var. *ramulosa* Chapman 1907, 129, pl. 9, fig. 9

Oolina ramulosa (Chapman, 1907); Yassini & Jones 1995, figs 363, 364, 366

***Oolina squamosa* (Montagu, 1803)** **Pl. 1, fig. 37**

Vermiculum squamosa Montagu 1803, 526, pl. 14, fig. 2.

Oolina squamosa (Montagu, 1803). Jones 1994, pl. 58, figs 28–32 (especially fig. 32); *Favulina squamosa* (Montagu, 1803); Li & McGowran 2000, 77, pl. 31, figs 31M-O (*partim*).

Remarks: I have followed Jones (1994) who outlined the range of names used for this form. It is a common species with little variation.

***Oolina subacuticostiformis* Albani & Yassini, 1989**

Pl.1, fig. 38

Oolina subacuticostiformis Albani & Yassini 1989, 389, fig. 4M

Remarks: Test robust, broadest below its equator and a little attenuated at the apertural end, with about 18 strong, flat-topped longitudinal costae from adapical to apical end; costae narrow towards each end. Costae terminate immediately before the aperture that may be the inner part of an ooline apertural collar with the surrounding rim lost.

***Oolina tasmanica* Parr, 1950** **Pl. 1, fig. 39**

Oolina tasmanica Parr 1950, 303, pl. 8, fig. 4; Hayward *et al.* 1999, 123, pl. 8, fig. 4.

Remarks: The figured specimen, while slightly affected by diagnesis, is typical of the form described by Parr (1950). Hayward *et al.* (1999) described *O. tasmanica* as having transverse costae that form a ring at the base. That is not obvious in Parr's description or illustration. The specimens recorded here have no evidence of the ring of transverse costae at the adapical end and thus conform closely with Parr's original illustration.

***Oolina* sp.1** **Pl. 1, fig. 40**

Oolina melo d'Orbigny, 1839. Yassini & Jones 1995, 113, figs 355 (not 353/354);

Remarks: A species with transverse costae at either apical or adapical end, but none with transverse costae over the entire test. It is intermediate between *O. melo* and *O. tasmanica*. Yassini & Jones (1995) recorded *O. melo* as a form dominated by longitudinal costae with transverse costae at the apical and adapical ends but essentially absent from the centre of the test. D'Orbigny's original specimen clearly has transverse costae throughout, more in keeping with the concept of the species of Hayward *et al.* (1999) and Albani & Yassini (1989). The specimens recorded here are of the same form as Yassini & Jones' (1995) figure 355, but not 353 or 354. Parr (1950) and Hayward *et al.* (1999) both refer to a ring of transverse costae at the adapical end but that must be very small as neither Parr nor Hayward *et al.* figure it.

***?Oolina* sp.** **Pl. 2, fig. 1**

Remarks: The form figured here is unusual in having a spherical body and two apertures, each on a short tube with simple opening. Similar forms in the same sample have a single aperture.

***Pseudofissurina* sp. 1** **Pl. 2, fig. 2**

Pseudofissurina sp. 1. Li & McGowran 2000, 82, pl. 32, fig. S

Remarks: This name is used in the same sense as by Li & McGowran (*op. cit.*). Apertural details are not available.

Family POLYMORPHINIDAE d'Orbigny, 1839

New genus and species **Pl. 2, figs 3, 4**

Remarks: A new widespread, large and prominent species, absent from the NPD1985 and other Flinders Island material seen to date, and relatively more common in section S12 where it makes up several percent of many faunas. It is a polymorphinid characterised by a short, simple polymorphinid initial section followed by a rectilinear uniserial series of chevron shaped chambers with terminal radiate aperture. It will be described formally elsewhere (Quilty & Whitehead in press).

***Globulina gibba* (d'Orbigny, 1826)**

Polymorphina (*Globuline*) *gibba* d'Orbigny 1826, 266.

Globulina gibba (d'Orbigny); Quilty 1974, 79, pl. 4, fig. 127; Li & McGowran 2000, 71, fig. 29W.

***Guttulina austriaca* d'Orbigny, 1846**

Guttulina austriaca d'Orbigny 1846, 223, pl. 12, figs 23-25: Cushman & Ozawa 1930, pl. 4, figs 3–5.

Remarks: Most specimens are typical of those with smaller numbers of chambers. Those in S12/4 are identified only tentatively because the chambers are more elongate than normal. The figured specimen from sample S12/1 is unusual in having a radiate aperture at each end.

***Guttulina communis* (d'Orbigny, 1826)** **Pl.2, fig. 5**

Polymorphina (*Guttuline*) *communis* d'Orbigny 1826, 266.

Guttulina communis (d'Orbigny): Quilty 1974, 79, pl. 4, figs 128, 129; Li & McGowran 2000, 69, figs 29M, N.

Guttulina problema d'Orbigny 1826, 266; Li & McGowran 2000, 70, fig. 29L

Remarks: Quilty (1974) could not differentiate *G. communis* from *G. problema* and that approach is followed here.

***Guttulina lactea* (Walker & Jacob, 1798)**

Serpula lactea Walker & Jacob 1798, 634, pl. 14, fig. 4.

Guttulina lactea (Walker & Jacob): Cushman & Ozawa 1930, 43, pl. 10, figs 1–4; Quilty 1974, 80, pl. 4, fig. 131.

***Guttulina regina* (Brady, Parker & Jones, 1870) Pl. 2, fig. 6**

Polymorphina regina Brady, Parker & Jones 1870, 241, pl. 41, figs 32a, b.

Guttulina regina (Brady, Parker & Jones): Quilty 1974, 81, pl. 4, figs 132–134; Li & McGowran 2000, 70, fig. 29P.

***Guttulina seguenzana* (Brady, 1884)**

Polymorphina seguenzana Brady 1884, 567, pl. 72, figs 16, 17.

Guttulina (*Sigmoidina*) *seguenzana* (Brady): Cushman & Ozawa 1930, 50, pl. 37, figs 8, 9.

***Pseudopolymorphina ligua* (Roemer, 1838)**

Polymorphina (*Polymorphinen*) *ligua* Roemer 1838, 385, pl. 3, figs 25a, b.

Pseudopolymorphina ligua (Roemer): Barker 1960, pl. 72, figs 9–11.

***Pseudopolymorphina subcylindrica* (Hantken, 1875)**

Polymorphina subcylindrica Hantken 1875, 51, pl. 14, fig. 14.

Pseudopolymorphina subcylindrica (Hantken): Cushman & Ozawa 1930, 107, pl. 28, fig. 2; Quilty 1974, 83, pl. 4, fig. 138; Li & McGowran 2000, 69, fig. 29J.

Remarks: The usage follows that of Li & McGowran (2000). The differences from *P. ligua* seem minor.

***Pyrulina angusta* (Egger, 1857)**
Polymorphina (*Globulina*) *angusta* Egger 1857, 290, pl. 13, figs 13–15.
Pyrulina angusta (Egger): Li & McGowran 2000, 71, fig. 29F.
***Pyrulina fusiformis* (Roemer, 1838)**
Polymorphina (*Globulinen*) *fusiformis* Roemer 1838, 386, pl. 3, fig. 37.
Pyrulina fusiformis (Roemer): Quilty 1974, 84, pl. 4, fig. 140; Li & McGowran 2000, 71, figs 29H, I.
***Pyrulina gutta* (d'Orbigny, 1826)**
Polymorphina (*Pyruline*) *gutta* d'Orbigny 1826, 267.
Pyrulina gutta (d'Orbigny): Quilty 1974, 84, pl. 4, fig. 141; Li & McGowran 2000, 71, fig. 29E.
***Sigmoidella elegantissima* (Parker & Jones, 1865)**
Polymorphina elegantissima Parker & Jones 1865, 438.
Sigmoidella elegantissima (Parker & Jones): Cushman & Ozawa 1930, 140, pl. 39, figs 1a–c; Quilty 1974, 85, pl. 4, fig. 142; Li & McGowran 2000, 70, fig. 29T.
***Sigmoidella kagaensis* Cushman & Ozawa, 1928** **Pl. 2, fig. 7**
Sigmoidella kagaensis Cushman & Ozawa 1928, 19, pl. 2, fig. 14; Cushman & Ozawa 1930, pl. 39, figs 2, 5.
Remarks: The species recovered here and an element of most samples, is large, with quadrate outline, and a strongly angled periphery on the ultimate chamber. It is relatively more elongate than the species figured under this name by Hayward *et al.* (1999, pl. 7, figs 13, 14). While numbers per sample may appear low, because of it size, it is a prominent species.
***Sigmomorphina* cf. *schwageri* (Karrer, 1877)**
Polymorphina schwageri Karrer 1877, 384, pl. 166, fig. 43.
Sigmomorphina schwageri (Karrer): Cushman & Ozawa 1930, 130, pl. 34, figs 1a, b.
Remarks: A single, large robust specimen that agrees well with the figures of Cushman & Ozawa (1930).

ORDER BULIMINIDA Fursenko, 1958
Superfamily BOLIVINACEAGlaessner, 1937
Family BOLIVINIDAE Glaessner, 1937
***Bolivina pseudoplicata* Heron-Allen & Earland, 1930**
Bolivina pseudoplicata Heron-Allen & Earland 1930, 81, pl. 3, figs 36–40; Quilty 1977, 76, pl. 1, fig. 26; Yassini & Jones 1999, 130, figs 549, 550, 554; Li & McGowran 2000, 89, figs 34 T, U.

Family BULIMINELLIDAE Hofker, 1951
*** *Elongobula arethusae* Revets, 1993** **Pl. 2, fig. 8**
Elongobula arethusae Revets 1993, 256, pl. 1. figs 6, 7; Jones 1994, 55, pl. 50, figs 24a, b.
Remarks: The presence of fine, roughly longitudinal striae on the surface of all but the last 20% of the test is characteristic. Revets (1993) illustrated *Elongobula arethusae* with striate test and Jones (1994) followed with a specimen with more finely striate test. This form has finer striae again.

Family BULIMINIDAE Jones, 1875
***Bulimina* cf. *aculeata* d'Orbigny, 1826**
Bulimina aculeata d'Orbigny 1826, 269; Li & McGowran 2000, 93, fig. 34C.
Remarks: The surface of most of the final whorl is smooth but the early part of the test is pustulose, this feature concentrated at the lower margin of each chamber showing a similarity with *B. aculeata* as illustrated by Li & McGowran (2000). There is a progression in concept from the apparently spineless form of Li & McGowran, through a weakly spined form of Hayward *et al.* (1999), to the highly spinose version of Jones (1994). The latter is truer to the original concept of *B. aculeata*. The spines typical of *B. aculeata* are not obvious.

Family SIPHOGENERINOIDIDAE Saidova, 1981
***Rectobolivina* sp.**
Remarks: This form, occurring only in NPD1985 is similar to *Rectobolivina striatula* (Cushman, 1922) but is compressed rather than circular in section.

Family UVIGERINIDAE Haeckel, 1894
***Trifarina* cf. *bradyi* Cushman, 1923**
cf. *Trifarina bradyi* Cushman 1923, 99, pl. 22, figs 3–9; Quilty 1977, 81, pl. 2, fig. 18; Li & McGowran 2000, 95, fig. 33BB.
Remarks: A tentative identification because of poor material, partly recrystallised and possibly with some fine costae.
***Uvigerina pliozea* (Vella, 1963)**
Hofkeruva (*Trigonouva*) *pliozea* Vella 1963, 8, pl. 2, figs 28, 29.
Uvigerina pliozea (Vella, 1963); Hornibrook *et al.* 1989, 158, fig. 37, 10.
***Uvigerina rodleyi* (Vella, 1963)**
Uvigerina sp. cf. *pigmaea* d'Orbigny: Parr 1939, 8, fig. 14
Hofkeruva (*Laminiuva*) *rodleyi* Vella 1963, 9, pl. 2, figs 28, 29.
Uvigerina (*Euuvigerina*) *rodleyi* (Vella, 1963): Hornibrook *et al.* 1989, 158, fig. 37:9
Remarks: An elongate, completely striate form but with striae discontinuous across sutures. It occurs only in Section S11, perhaps reflecting a difference in nutrient supply to the infauna. It is likely to be the form identified by Parr (1939, fig. 14) as *U.* sp. cf. *pigmaea* d'Orbigny).

Superfamily CASSIDULINACEA d'Orbigny, 1839
Family CASSIDULINIDAE d'Orbigny, 1839
***Globocassidulina subglobosa* (Brady, 1881)**
Cassidulina subglobosa Brady 1881, 60 (figures in Brady 1884, pl. 54, fig. 17).
Globocassidulina subglobosa (Brady): Quilty 1982, 29, pl. 4, figs 23, 24; Li & McGowran 2000, 97, figs 35DD, EE.
Remarks: A few specimens in NPD1985, including one with thinner wall and depressed sutures, that may belong to a different species.

Superfamily TURRILINACEA Cushman, 1927
Family STAINFORTHIIDAE Reiss, 1963
*** *Virgulopsis* sp.** **Pl. 2, fig. 9**
Remarks: A single well-preserved specimen in NPD1985. It has the same degree of hispid surface and body form as *Uvigerina auberiana* d'Orbigny (Jones 1994, 86, pl. 75, fig. 9) but lacks the elongate tubular aperture, instead having a *Virgulopsis* aperture.

ORDER ROTALIIDA Lankester, 1885
Superfamily ACERVULINACEA Schultze, 1854
Family ACERVULINIDAE Schultze, 1854
***Sphaerogypsina globulus* (Reuss, 1848)**
Ceriopora globulus Reuss 1848, 33, pl. 5, fig. 7.
Gypsina globulus (Reuss): Loeblich & Tappan 1994, 154, pl. 334, figs 4-6; Quilty 1982, 15, pl. 2, fig. 15.
Sphaerogypsina globula (Reuss): Li & McGowran 2000, 127, figs 45E, F.

Superfamily CHILOSTOMELLACEA Brady, 1881
Family ALABAMINIDAE Hofker, 1951
***Alabamina tenuimarginata* (Chapman, Parr & Collins, 1934)**
Pulvinulinella tenuimarginata Chapman, Parr & Collins 1934, 565, pl. 9, figs 19a-c.
Alabamina tenuimarginata (Chapman, Parr & Collins): Carter 1964, 114, pl. 11, figs 220–222; Quilty 1982, 33, pl. 5, figs 11, 12; Li & McGowran 2000, 107, figs 39M–O.

Family GAVELLINELLIDAE Hofker, 1956

***Discanomalina vermiculata* (d'Orbigny, 1839) Pl. 2, figs 10-12**

Truncatulina vermiculata d'Orbigny 1839, 39, pl. 6, figs 1-3.

Discanomalina vermiculata (d'Orbigny): Jones 1994, 101, pl. 97, fig. 7; Li & McGowran 2000, 116, figs 42D–F.

Remarks: The identification is tentative as comparison figures are not ideal. The material consists of specimens closest to Li & McGowran's (2000) fig. 41D with regular *Cibicides*-like dorsal surface and with final few chambers extending well over the periphery. Ventral surface completely involute.

***Gyroidina neosoldanii* Brotzen, 1936**

Rotalia soldanii (d'Orbigny): Brady 1884, pl. 107, figs 6, 7.

Gyroidina neosoldanii Brotzen 1936, 158: Quilty 1982, 34, pl. 5, figs 21–23: Li & McGowran 2000, 116, fig. 39R

Remarks: A single specimen in S11/43

Family HETEROLEPIDAE Gonzalez-Donoso, 1969

***Anomalinoides fasciatus* (Stache, 1864)**

Rotalia fasciata Stache 1864, 281, pl. 24, fig. 31.

Anomalinoides fasciatus (Stache): Hornibrook *et al.* 1989, 85, figs 18.7a, b: Li & McGowran 2000, 115, figs 42L–N.

Remarks: The ventral aspect is appropriate but the dorsal surface is too poor for positive identiication.

***Anomalinoides nonionoides* Parr, 1939**

Anomalina nonionoides Parr 1939, 231, pl. 22, figs 38a–c.

Anomalinoides nonionoides Parr 1939; Carter 1964, 100, pl. 8, figs 154–156; Quilty, 1982, 37, pl. 6, figs 11–13; Li & McGowran, 2000, 115, figs 42Q, R.

Remarks: The form is similar to that figured by Carter (1964) as *A. nonionoides* (Parr) but has more deeply impressed umbilici.

***Heterolepa brevoralis* (Carter, 1958)**

Cibicides brevoralis Carter 1958, 47, pl. 6, figs 54–56.

Cibicidoides brevoralis (Carter): Quilty 1982, 11, pl. 1, figs 26, 27.

Heterolepa brevoralis (Carter): Li & McGowran 2000, 115, figs 40A–C.

Remarks: A very tentative identification based on general shape and profile, number of chambers and lobulate periphery. Characteristic apertural details not visible.

Family ORIDORSALIDAE Loeblich & Tappan, 1984

***Mesorotalia* sp. Pl. 2, figs 13, 14**

Remarks: This unidentified (perhaps new) species has a very low domed dorsal and flat ventral surface. Rate of increase of chamber height is very low. Smooth dorsal surface has small slitlike apertures along the intercameral sutures for the entire final whorl but not earlier. Some of the apertures are accompanied by small circular openings. The primary aperture is interiomarginal on the ultimate chamber on the ventral surface; chamber surface immediately below the aperture is papillate.

Yassini & Jones (1995, figs 844–845, 850–851) described *M. rara* from Recent sediments of the south coast of New South Wales. It differs from this form in that the entire ventral surface is papillate.

Superfamily DISCORBINELLACEA Sigal, 1952

Family DISCORBINELLIDAE Sigal, 1952

***Discorbinella araucana* (d'Orbigny, 1839)**

Rosalina araucana d'Orbigny 1839, 44, pl. 6, figs 10, 11.

Discorbinella araucana (d'Orbigny): Quilty, 1977, 82, pl. 2, figs 23–25; Jones 1994, 93, pl. 86, figs 10, 11.

Remarks: This species is rare and it may also equate to what Li & McGowran (2000) referred to as *D. scopos* (Finlay 1940).

***Discorbinella bertheloti* Cushman, 1924**

Discorbinella bertheloti Cushman 1924, 33, pl. 10, fig. 1: Jones 1994, 95, pl. 89, figs 10–12; Li & McGowran 2000, 103, pl. 38, N, O.

***Discorbinella papillata* (Chapman, Parr & Collins, 1934)**

Discorbis bertheloti var. *papillata* Chapman, Parr & Collins 1934, 561, pl. 9, figs 14a–c.

Discorbinella papillata (Chapman, Parr & Collins, 1934): Carter 1964, 87, pl. 5, figs. 105–107.

Planulina papillata (Chapman, Parr & Collins, 1934): Li & McGowran 2000, 111, pl. 38T, U

Remarks: On some specimens, the papillae are only weakly developed and the dorsal surface is a little more highly vaulted than is typical as illustrated by Carter (1964).

The species is characterised by flat ventral and dorsal surfaces, the former with markedly raised ridge-like intercameral sutures that break into nodes proximally, more so on earlier chambers. Ventral surface smooth with subtle straight intercameral sutures and a central, slitlike aperture with low simple rim.

***Discorbinella timida* Hornibrook, 1961**

Discorbinella timida Hornibrook 1961, 116, pl. 14, figs 288, 293, 297; Hayward *et al.* 1999, 152, pl. 14, figs 13–15.

Remarks: It seems possible that forms described by Yassini & Jones (1995) as *Milesina differens* McCulloch, 1977 and *M. splendida* Yassini & Jones, 1995 refer to this species.

***Discorbinella* cf. *vitrevoluta* (Hornibrook, 1961) Pl. 2, figs 15, 16**

? *Discorbis williamsoni* Chapman & Parr, Parr 1932, 226, l. 21, fig. 25. cf. *Rosalina vitrevoluta* Hornibrook 1961, 102, pl. 13, figs 275–277.

cf. *Discorbinella vitrevoluta* (Hornibrook, 1961); Hayward *et al.* 1999, 153, pl. 14, figs 16–18.

?*Orbitina carinata* Sellier de Civrieux 1977, 29, pl. 18, figs 3-10; Loeblich & Tappan 1994, 137, pl. 275, figs 7–12; Revets 2000, pl. 4, figs 35, 36.

Remarks: Hayward *et al.* (1999) illustrated a specimen as *Discorbinella vitrevoluta* (Hornibrook) and it is arguably conspecific with this species. It is not so clear that it is the form decribed by Hornibrook (1961) as *Rosalina vitrevoluta*. This species is represented by many specimens, often well-preserved, and seems to be the first record as a fossil. It is very similar to what Loeblich & Tappan (1994) and Yassini & Jones (1995) figured as *Orbitina carinata* Sellier de Civreux, 1977. A characteristic of the species figured by Hayward *et al.* (1999) and Yassini & Jones (1995) but not by Hornibrook (1961) is that the dorsal intercameral sutures are distinctly raised near the periphery, as a continuation of the peripheral thickening, but gently depressed proximally. It may also be the form discussed and illustrated by Parr (1932) as *Discorbis williamsoni* and foreshadowed for publication in Parr (1950), although it was not so described in Parr (1950). The name *Orbitina* may be a junior homonym of the European Decollate Snail described by Linné (1758) as *Rumina decollata* and later re-described as *Orbitina incomparabilis* and *O. truncatella* by Germain (1930).

***Discorbinella* sp. 1**

Remarks: A single specimen with distinctly limbate dorsal sutures, and strongly recurved ventral sutures. It is very similar in gross appearance to *Planulina wuellerstorfi* (Schwager, 1866) but is smaller, more compressed, has gently pustulose chamber walls and a discorbinellid ventral surface.

***Laticarinina altocamerata* (Heron-Allen & Earland, 1922)**

Truncatulina tenuimargo Brady var. *alto-camerata* Heron-Allen & Earland 1922, 209, pl. 7, figs 24–27.

Parvicarinina altocamerata (Heron-Allen & Earland): Hornibrook 1961, 118, pl. 14, figs 296, 299, 301, 302, 305; Jones 1994, 97, pl. 93, figs 2a–c.

Laticarinina alatocamerata (Heron-Allen & Earland): Yassini & Jones 1995, 165, figs 981–983.

Remarks: The single specimen recovered is very well-preserved and lacks a broad marginal flange but has the pronounced tubercles on the extreme ventral aspect of chambers.

Family PSEUDOPARRELLIDAE Voloshinova, 1952

***Planulinoides biconcavus* (Jones & Parker, 1862)**

Discorbina biconcava Jones & Parker 1862 in Carpenter, Parker & Jones 1862, 201, pl. 32g.

Discorbinella biconcava (Jones & Parker): Carter 1964, 86, pl. 5, figs 97–100.

Planulinoides biconcava (Jones & Parker): Quilty 1977, 87, pl. 3, fig. 28.

Planulina biconcava (Jones & Parker): Li & McGowran 2000, 111, figs 38V–X.

Remarks: A pervasive but never major component of the faunas. Placed by Quilty (1977) and Loeblich & Tappan (1987) in *Planulinoides*.

Superfamily DISCORBACEA Ehrenberg, 1838

Family BAGGINIDAE Cushman, 1927

***Baggina phillipinensis* (Cushman, 1921)**

Pulvinulina philippinensis Cushman 1921, 331, pl. 58, fig. 2.

Baggina philippinensis (Cushman): Carter 1964, 85, pl. 5, figs 94–96: Quilty 1977, 89, pl. 4, figs 15, 16: Li & McGowran 2000, 99, fig. 37A.

****Parredicta kalimnensis* (Parr, 1939)** **Pl. 2, figs 17, 18**

Planulina kalimnensis Parr 1939, 69, pl. 1, figs. 19a–c.

Valvulineria kalimnensis (Parr): Carter 1964, 101, pl. 8, figs. 157–167: Quilty 1982, 9, pl. 1, figs 15–18.

Parredicta kalimnensis (Parr). Li & McGowran 1995, 101, figs. 37 B–D.

Remarks: This is by far the dominant species in the Flinders Island material. Preservation varies from excellent (normal) to very fragmentary (less commonly) indicating that the environment in the Pliocene was, at times, high energy, but not such that all material was damaged. A significant proportion of species include as "unidentified" probably represents this species.

Parr (1939) stated that this is the typical species of the Kalimnan.

Family EPONIDIDAE Hofker, 1951

***Eponides repandus* (Fichtel & Moll, 1798)**

Nautilus repandus Fichtel & Moll 1798, 35, pl. 3, figs a-d.

Eponides repandus (Fichtel & Moll): Quilty 1982, 7, pl. 1, figs 3, 4.

Eponides rapandus (Fichtel & Moll): Li & McGowran 2000, 103, fig. 36Y.

Remarks: A single broken, poorly preserved unfigured specimen in S12/1, identified tentatively.

Family DISCORBIDAE Ehrenberg, 1838

***Discorbis balcombensis* Chapman, Parr & Collins, 1934**

Discorbis balcombensis Chapman, Parr & Collins 1934, 562, pl. 8, figs 10a–c: Carter 1964, 77, pl. 3, figs 64–66; Quilty 1977, 84, pl. 3, figs 5–8, 11-13; Li & McGowran 2000, 104, figs 37T–V.

***Lamellodiscorbis dimidiatus* (Jones & Parker, 1862)**

Discorbina dimidiatus Jones & Parker, in Carpenter, Parker & Jones 1862, 201, fig. 32B

Lamellodiscorbis dimidiata (Jones & Parker): Bermudez 1952, 39; Hansen & Revets 1992, 176, pl. 4, figs. 1–3, 7, 8.

Trochulina dimidiata (Jones & Parker): Yassini & Jones 1995, 158, figs. 916, 917; Hayward *et al.* 1999, 139, pl. 10, figs. 9–11.

Remarks: Occurs in only one sample and is poorly preserved.

***Neoeponides procerus* (Brady, 1881)**

Pulvinulina procera Brady, 1881, 16 (figures Brady 1884, pl. 105, figs 7a–c)

"Eponides ?" procera (Brady): Barker 1960, pl. 105, figs 7a–c.

Family ROSALINIDAE Reiss, 1963

***Neoconorbina* cf *pacifica* Hofker, 1951**

cf. *Neoconorbina pacifica* Hofker 1951, 438, figs 302, 303; Hayward *et al.* 1999, 141, pl. 10, figs 21–23.

Remarks. The name applied tentatively to a specimen with hemispherical dorsal surface with flush sutures and non-lobulate periphery; apertural details not clear.

****Planodiscorbis* sp.** **Pl. 2, figs 19, 20**

Remarks: This species, occurring as a single specimen, is marked by a gently domed, finely perforate involute dorsal surface of eight chambers in the final whorl and depressed intercameral sutures that are gently recurved distally. No later thickening. Coarse pores on ealier chambers may be due to later boring. A marked keel. Ventral surface flat or gently concave, apparently imperforate with small isolated central boss. Aperture with slightly flared rim continues from dorsal surface across the periphery to continue along the base of the final chamber and link with those of earlier four or five chambers, but with a re-entrant at each ventral intercameral suture. The most distinguishing feature is the projecting anteroperipheral margin of the final whorl. This form belongs to the same genus as *Cibicidina walli* Bandy, 1949 as figured by van Morkhoven *et al.* (1986, pl. 60) but has eight chambers in the final whorl. *C. walli* is very reminiscent of *Planodiscorbis* sp. nov. of Jones (1994 pl. 90, figs 1a–c) and is likely to be the same species. It differs from *P. rarescens* in having a distinctly projecting anteroperipheral aspect of the final whorl.

***Rosalina australis* (Parr, 1932)**

Discorbis australis Parr, 1932, 227, pl. 22, fig. 31.

Rosalina australis (Parr, 1932): Jones 1994, 94, pl. 87, figs 5–7; Yassini & Jones, 1995, 159, fig. 768.

Remarks: This robust species is uncommon and the specimen in NPD1985 is distorted.

***Rosalina bradyi* (Cushman, 1915)**

Discorbis globularis (d'Orbigny) var. *bradyi* Cushman 1915, 12, pl. 8, figs 1a–c.

Rosalina bradyi (Cushman): Jones 1994, 93, pl. 86, figs 8a–c; Yassini & Jones, 1995, 159, fig. 767: Hayward *et al.* 1999, 142, pl. 11, figs 1–3: Li & McGowran 2000, 104, figs 38F, G.

***Rosalina mitchelli* Carter, 1964**

Rosalina mitchelli Carter 1964, 73, pl. 3, figs 54–56; Quilty 1977, 88, pl. 4, figs 9, 10.

***Rosalina vilardeboana* d'Orbigny, 1839**

Rosalina vilardeboana d'Orbigny 1839, 44, pl. 6, figs 13–15; Quilty 1977, 89, pl. 4, figs 11, 12; Jones 1994, 93, pl. 86, figs 9a–c; Li & McGowran 2000, 105, figs 38J, K.

***Rosalina* sp. 1**

Remarks: A low domed form normally revealing little detail. Preservation is poor. The ventral surface seems to be depressed to a plane generally below a very thick periphery. A similar form may be *Neoconorbina pacifica* Hofker (Hayward *et al.* 1999, pl. 10, figs 21–23.

***Rosalina* sp. 3**

Remarks: This form occurs in only one sample. It lacks the imperforate zone on the apertural face typical of *Cancris auriculus* (Fichtel & Moll, 1798), which it resembles initially, and the ventral surface is esentially flat. The high rate of increase of chamber height is unusual for *Rosalina*.

Superfamily GLABRATELLACEA Loeblich & Tappan, 1964

Family GLABRATELLIDAE Loeblich & Tappan, 1964

***Pileolina australensis* (Heron-Allen & Earland, 1932)**

Discorbis australensis Heron-Allen & Earland 1932, 416.

Pileolina (?) *australensis* (Heron-Allen & Earland): Barker 1960, 184, pl. 89, figs 2–4.

Pileolina australensis (Heron-Allen & Earland): Quilty 1977, 94, pl. 5, fig. 17.

Glabratella australensis (Heron-Allen & Earland): Jones 1994, 95, pl. 89, figs 2–4; Yassini & Jones 1995, 160, figs 731–734.

Remarks: A single plastogamic pair. Hayward *et al.* (1999) gave a good justification for the retention of the generic name of *Pileolina*

for this group of species. They used widespread use in New Zealand as a justification but the genus also is well-known in Australia.

***Planoglabratella opercularis* (d'Orbigny, 1826)**

Rosalina opercularis d'Orbigny 1826, 271, modeles no. 7

Pileolina (?) *opercularis* (d'Orbigny): Barker 1960, pl. 89, figs 8, 9.

Planoglabratella opercularis (d'Orbigny): Hayward *et al.* 1999, 148, pl. 13, figs 1–3.

Remarks: A few poor specimens, partly recrystallised.

Family HERONALLENIIDAE Loeblich & Tappan, 1986

***Heronallenia lingulata* (Burrows & Holland, 1895)**

Discorbina lingulata Burrows & Holland, 1895, in Jones 1895, pl. 7, figs 33a–c.

Heronallenia lingulata (Burrows & Holland): Chapman, Parr & Collins 1934, 564, pl. 8, figs 11a–c; Carter 1964, 92, pl. 6, figs 124–126; Quilty 1977, 93, pl. 5, figs 13, 14; Hayward *et al.* 1999, 148, pl. 13, figs 4–6; Li & McGowran 2000, 106, figs 37O, P.

Remarks: Apertures on chamber wall are open in last few chambers but closed on earlier chambers.

***Heronallenia parri* Carter, 1958**

Heronallenia parri Carter 1958, 43, pl. 5, figs 43–45; Carter 1964, 92; Quilty 1977, 93, pl. 5, figs 15, 16; Li & McGowran 2000, 106, fig. 37Q.

Remarks: This small species has a disjunct distribution and I question whether it is distinct from *H. lingulata* which may be the mature larger form.

Superfamily NONIONACEA Schultze, 1854

Family NONIONIDAE Schultze, 1854

****Astrononion novozealandicum* Cushman & Edwards, 1937 Pl. 2, fig. 21**

Astrononion novozealandicum Cushman & Edwards 1937, 35, pl. 3, figs 18a,b

Astrononion novozealandicum Cushman & Edwards, 1937; Hayward *et al.* 1999, 157, pl. 15, figs 8, 9

Remarks: This is the most common species of *Astrononion* but still is rare, with about 10–11 chambers in the final whorl and sutural apertures less distinct on earlier chambers. The zone between the apertural sutures and the umbilicus is smooth and apparently imperforate, in contrast with the periphery. Umbilicus is closed. The characteristic pit is seldom as well developed as illustrated by Hayward *et al.* (1999).

***Astrononion obesum* Carter, 1964**

Astrononion obesum Carter 1964, 112, pl. 10, figs 205, 206.

Remarks: Specimens are uncommon and only tentatively placed here. They have inflated chambers, depressed sutures and about eight chambers in the final whorl.

***Astrononion tasmaniensis* Carter, 1964**

Astrononion tasmaniensis Carter 1964, 111, pl. 10, figs 203, 204: Quilty 1982; 31, pl. 5, figs 4, 5.

****Pseudononion victoriense* (Cushman, 1936) Pl. 2, fig. 22**

Nonion victoriense Cushman 1936, 67, pl. 12, figs 10a, b; Carter 1964, 109, pl. 10 figs 201, 202; Li & McGowran 2000, 122, figs 43M, N.

Florilus victoriensis (Cushman): Quilty 1982, 31, pl. 5, fig. 6.

Remarks: Quilty (1982) placed this species in *Florilus* but that is an invalid genus and Loeblich & Tappan (1987) noted that submission had been made to the ICZN to suppress the name; thus *Pseudononion* now seems more appropriate. This is one of the dominant species throughout the sections studied and, with *Parredicta kalimnensis* is the characteristic of the faunas.

Superfamily PLANORBULINACEA Schwager, 1877

Family CIBICIDIDAE Cushman, 1927

***Cibicides cygnorum* Carter, 1964**

Cibicides cygnorum Carter 1964, 98, pl. 7, figs 139–144: Li & McGowran 2000, 113, figs 41O, P.

****Cibicides ihungia* Finlay, 1940 Pl. 3, figs 1, 2**

Cibicides ihungia Finlay 1940, 465, pl. 67, figs 201–206; Hornibrook 1961, 162, pl. 24, figs 488, 189; Li & McGowran 2000, 113, figs 41E, F.

****Cibicides thiara* (Stache, 1864) Pl. 3, figs 3, 4**

Remarks: A few poor specimens in NPD.

****Cibicides* sp. 1 Pl. 3, figs 5–7**

Remarks: This is one of the most abundant species, making up to 19% of faunas. It is characterised by a robust, regular, thick test with up to 12 chambers in the final whorl. Finely perforate throughout. Dorsal surface flat to gently convex; sutures flush early and slightly depressed later; recurved little peripherally. Periphery varying from moderately to broadly rounded, not keeled. Ventral surface a high dome with marked central boss; sutures initially flush, slightly depressed later, recurved distally; boss merging with chamber walls. Aperture interiomarginal on the ventral side.

It is distinguished by thick test, number of chambers per whorl, ventral boss and rounded periphery.

****?Cibicides* sp. 2 Pl. 3, figs 8, 9**

Remarks: The dorsal surface is evolute with about five coarsely perforate chambers; intercameral sutures swept back and raised near the periphery. Periphery gently lobulate, with clear keel. Ventral surface completely involute with inflated chambers, straight radial slightly depressed intercameral sutures and high interiomarginal aperture. Shape very reminiscent of *Oridorsalis umbonatus* (Reuss, 1851) but with no hint of dorsal apertures. Van Morkhoven *et al.* (1986) figured *Cibicidoides* sp. 14 that is grossly similar but has the typical cibicidid small peripheral aperture. Yassini & Jones (1995) also figured *Cibicidoides* spp. but their specimens, while having the coarsely perforate dorsal surface, have too many chambers per whorl.

Genus DYOCIBICIDES Cushman & Valentine, 1930

Dyocibicides is a common element of most samples. While the generic name probably has no biological validity and species allocated to it are variants of various species of *Cibicides* such as *C. mediocris* Finlay, 1940, the three morphotypes described – *D. biserialis* Cushman & Valentine, 1930, *D. primitiva* Vella, 1957, and *D. uniserialis* Thalmann, 1933 – can be recognised in the Flinders Island samples. All were probably attached during life and this has had a significant influence on the form taken. Often, there is evidence of attachment to a straight, narrow cylindrical body, perhaps a small echinoid spine. Most were probably attached to something flat such as an algal thallus.

***Dyocibicides primitiva* Vella, 1957**

Dyocibicides primitiva Vella 1957, 41, pl. 9, figs 198–200; Li & McGowran 2000, 114, figs 41T, V.

Remarks: The most common form seen and marked by irregular growth of a few chambers following an early regular *Cibicides* coil.

****Dyocibicides biserialis* Cushman & Valentine, 1930 Pl. 3, fig. 10**

Dyocibicides biserialis Cushman & Valentine 1930, 30, pl. 10, figs 1, 2; Quilty 1982, 13, pl. 2, figs 7, 8; Li & McGowran 2000, 114, fig. 41U.

Remarks: Recognised by development of a short series of almost regular biserial chambers.

***Dyocibicides uniserialis* Thalmann, 1933**

Dyocibicides uniserialis Thalmann 1933, 254; Li & McGowran 2000, 114, pl. 41W, Y.

Remarks: Uncommon in Flinders Island samples and the name is applied only when the final chamber has a circular terminal aperture with rim.

Superfamily PLANORBULINACEA
Family PLANORBULINIDAE Bermúdez, 1952

***Planorbulina mediterranensis* d'Orbigny, 1826**

Planorbulina mediterranensis d'Orbigny 1826, 280, pl. 14, figs 4-6; Quilty 1982, 14, pl. 2, fig. 9.

Remarks: Occurs as single specimens in only two samples, but attests to the existence of substrate for attachment.

Family PLANULINIDAE Bermúdez, 1952

***Planulina ariminensis* d'Orbigny, 1826**

Planulina ariminensis d'Orbigny 1826, 280, pl. 14, figs 1–3.

Remarks: A few poor specimens are placed here tentatively.

Superfamily ROTALIACEA Ehrenberg, 1839
Family ELPHIDIIDAE Galloway, 1933

***Discorotalia aranea* (Hornibrook, 1958)**

Notorotalia aranea Hornibrook 1958, 662, figs 12–14.

Discorotalia aranea (Hornibrook): Hayward *et al.* 1997, 95, pl. 18, figs 4–6.

Genus *Elphidium*

Elphidium is one of the most diverse species groups and commonly constitutes about 10% of any sample. Hayward *et al.* (1997) used a "lumpers" approach to the generic concept of *Elphidium* and that is the approach followed here. They then seem to have employed a "splitters" approach at species level. There are some anomalies, one of the most important of which involves the concept of *E. advenum advenum.* While noting that it is extant, it is listed as becoming extinct in the mid-Late Miocene in the New Zealand region but is an important part of the faunas recorded here. A problem palaeontologically lies in the value of the distribution of papillae which may be very fine and easily affected by diagenesis.

****Elphidium advenum advenum* (Cushman, 1930)** **Pl. 3, fig. 12**

Polystomella advena Cushman 1922, 56, pl. 9, figs 11, 12.

Elphidium advenum advenum (Cushman): Hayward *et al.* 1997, 65, pl. 2, figs. 9–18.

Remarks: This is an abundant form throughout both sections and in NPD1985. As noted by Hayward *et al.* (1997) it is quite variable and best identified as a population rather than on every specimen.

***Elphidium advenum limbatum* (Chapman, 1907)**

Polystomella macellum var. *limbatum* Chapman 1907, 142, pl. 10, figs 9a, b.

Elphidium limbatum (Chapman): Collins 1958, 421.

Elphidium advenum limbatum (Chapman): Hayward *et al.* 1997, 67, pl. 3, figs 9–17; pl. 4, figs 1–10.

***Elphidium advenum maorium* Hayward, 1997**

Elphidium advenum maorium Hayward 1997 in Hayward *et al.* 1997, 69, pl. 1, fig. 7, pl. 4, figs 11–16, pl. 5, figs 1–5.

****Elphidium craticulatum* (Fichtel & Moll, 1798) Pl. 3, fig. 11**

Nautilus craticulatus Fichtel & Moll 1798, 51, pl. 5, figs h, i, k.

Elphidium craticulatum (Fichtel & Moll): Cushman 1933, 48, pl. 11, figs 5a, b; Hayward *et al.* 1997, 73, pl. 7, figs 5–12.

****Elphidium crispum crispum* (Linné, 1758)** **Pl. 3, fig. 13**

Nautilus crispus Linné 1758, 709.

Elphidium crispum (Linné): Cushman 1933, 47, pl. 11, fig. 4.

Elphidium crispum crispum (Linné): Hayward *et al.* 1997, 74, pl. 7, figs 13–16; pl. 8, figs 1–9.

Remarks: This is a medium to large form and the specimens recorded, while in lateral view identical to Hayward *et al.*'s (1997) figures, are generally more compressed than their figures would indicate. It is marked by a distinct rhomboidal profile and high number of chambers that are narrow, almost ridge-like on the surface. It has some similarities with *E. advenum tongaense* (Cushman).

Some specimens recorded as *E. crispum* have a rounded periphery (acutely rounded in the terms of Hayward *et al.*) rather than acute and keeled. Species counts may include specimens of *E. pseudonodosum* Cushman stated by Parr (1939) to be characteristic of the Kalimnan although he recorded it only from the Kalimnan of the Hamilton region of western Victoria.

The form identified earlier as *E.* cf. *hawkesburyense* (Albani) (Quilty 1985) is likely to be of this species but is poorly preserved. It has a stellar arrangement of incised proximal intercameral sutures as well illustrated by Hayward *et al.* (1997, especially pl. 9, fig. 12.). Some poorly preserved specimens with deeply incised sutures may approach *Elphidium sandiegoense* (Lankford, 1973).

***Elphidium excavatum excavatum* (Terquem, 1875)**

Polystomella excavata Terquem 1875, 25, pl. 2, figs 2a–f.

Elphidium excavatum (Terquem): Murray 1971, 159, pl. 66, figs 1–7.

Elphidium excavatum excavatum (Terquem): Hayward *et al.* 1997, 77, pl. 1, figs 3, 12, pl. 9, figs 9–18.

***Elphidium tongaense* (Cushman, 1931)**

Ozawaia tongaense Cushman 1931, 80, pl. 10, figs 7–10: Loeblich & Tappan 1987, 675, pl. 791, figs 1–4.

Elphidium advenum tongaense (Cushman): Hayward *et al* 1997, 71, pl. 5, figs 13–18.

Remarks: This rather unusual form has the same lateral aspect as *E. advenum limbatum* (Chapman) but is much more highly compressed. The degree of compression is such that forms intermediate between this and *E. a. limbatum* do not occur.

****Elphidium* sp. 1** **Pl. 3, fig. 14**

Remarks: This very rare species, occurring only in NPD1985, is of the *E. novozealandicum* group. It is highly compressed and differs from *E. novozealandicum* and *E.* aff. *novozealandicum* as discussed by Hayward *et al.* (1997) in having too few (about 14) chambers in the final whorl and only some 10 septal bridges.

****Notorotalia clathrata* (Brady, 1884)** **Pl. 3, figs 15, 16**

Rotalia clathrata Brady 1884, 709, pl. 107, fig. 8.

Notorotalia clathrata (Brady): Carter 1964, 124, pl. 13, figs 256–259; Li & McGowran 2000, 125, figs 45A–C.

Remarks: *Notorotalia* is common in most samples, one of the dominant species of the entire study. It is taken to be a single species but may be two. The difficulty in differentiation is due to the fact that some specimens have a smooth dorsal surface and a ventral plug while others have the typical *N. clathrata* surface. The smooth dorsal surface may arise from original condition or from abrasion. Chamber arrangement is typical of *N. clathrata.*

****Parrellina imperatrix* (Brady,1881)** **Pl. 3, fig. 17**

Polystomella imperatrix Brady 1881, 66: Brady 1884, pl. 110, figs. 13–15.

Parrellina imperatrix (Brady): Thalmann 1951, 224; Hayward *et al.* 1997, 96, pl. 18, figs. 10–12; Li & McGowran, 2000, 125, figs 44D, E.

Elphidium imperatrix (Brady): Carter 1964, 120, pl. 12, figs. 247–249.

Remarks. Hayward *et al.* (1997) regarded this as a modern species but Carter (1964) and Li & McGowran (2000) recorded it in older sections from southeastern Australia.

****Parrellina verriculata* (Brady, 1881)** **Pl. 3, fig.18**

Polystomella verriculata Brady 1881, 66 (figures Brady 1884, pl. 110, fig. 12).

Parrellina verriculata (Brady): Hofker 1969, 478, figs 74–76, 79–85; Hayward *et al.* 1997, 97, pl. 19, figs 1–3.

Remarks: This species varies from umbonate with pores, to involute, and from parallel-sided to lenticular. The differentiation from *P. imperatrix* on the basis of a few strong spines, while technically simple, would appear to be without biological foundation. Following tradition, they are differentiated herein.

***Parrellina* sp.**

Remarks: Two unidentifiable fragments in NPD1985.

ORDER GLOBIGERINIDA Lankester, 1885
Superfamily GLOBOROTALIACEA Cushman, 1927
Family GLOBOROTALIIDAE Cushman, 1927

***Globorotalia crassaformis* (Galloway & Wissler, 1927)** **Pl. 4, fig. 11**

Globigerina crassaformis Galloway & Wissler 1927, 41, pl. 7, fig. 12: Kennett & Srinivasan 1983, 146, pl. 34, figs 6–8; Hornibrook 1982, 93, fig. 6d–w; Hornibrook *et al.* 1989, 129, figs 29.10, 30.1a–c.

Remarks: Hornibrook *et al.* (1989) listed a FAD for non-keeled specimens of this species, and *G. puncticulata*, of 5 Ma, the basis for the oldest estimate of age of the samples.

***Globorotalia mons* Hornibrook, 1982** **Pl. 4, figs 15–17**

Globorotalia conomiozea mons Hornibrook 1982, 91, figs 3a–g, 4a–i.
Globorotalia mons Hornibrook: Hornibrook *et al.* 1989, 132, figs 29.2a, b, 32.

Remarks: A very characteristic species that bridges the boundary between New Zealand Kapitean and Opoitian stages. The co-occurrence with *G. crassaformis* and *G. puncticulata* ensures that the age is Early Opoitian.

***Globorotalia 'obesa'* Bolli, 1957** **Pl. 4, fig. 18**

Globorotalia obesa Bolli 1957, 119, pl. 29, figs 2a–3.
Globigerinella obesa (Bolli): Kennett & Srinivasan 1983, 234, pl. 59, figs 2–5

Remarks: This species is interpreted a little broadly to include common planktonic species in NPD1985. Specimens are small, thin-walled have 4½ chambers in the final whorl and the apertures vary from those that are moderate to high with no lip or rim (typical *G. obesa*), those that are moderately high with poorly developed rim and rarely even a small tooth (could be termed *Globigerina angustiumbilicata* Bolli), to those in which the aperture is large and merges with that of the previous chamber (*Globigerina bulloides concinna* Reuss of Blow 1969).

***Globorotalia pliozea* Hornibrook, 1982** **Pl. 4, figs 13, 14**

Globorotalia pliozea Hornibrook 1982, 95, figs 7a–g; Hornibrook *et al.* 1989, 133, figs 29, 6a, b.

Remarks: This species forms (with *G. mons*) a convenient link with the New Zealand biostratigraphic subdivision of the Late Neogene.

***Globorotalia puncticulata* (Deshayes, 1832)** **Pl. 4, fig. 12**

Globigerina puncticulata Deshayes 1832, 170: Banner & Blow 1960, 15, pl. 5, figs 7a–c.
Globorotalia puncticulata (Deshayes): Kennett & Srinivasan 1983, 116, pl. 27, figs 4–6.

***Neogloboquadrina humerosa* (Takayanagi & Saito, 1962)** **Pl. 4, figs 9, 10**

Globorotalia humerosa Takayanagi & Saito 1960, 78, pl. 28, figs 1a–2b.
Neogloboquadrina humerosa (Takayanagi & Saito, 1962): Kennett & Srinivasan 1983, 196, pl. 48, figs 4–6.

***Neogloboquadrina pachyderma* (Ehrenberg, 1861)** **Pl. 4, fig. 8**

Aristospira pachyderma Ehrenberg 1861, 276.
Globorotalia pachyderma (Ehrenberg): Vilks, 1975, 321, pl. 1 figs. 1–3, pl. 2, figs. 1–3.
Neogloboquadrina pachyderma (Ehrenberg): Kennett & Srinivasan 1980, 148, pl. 3, figs 1–13: Kennett & Srinivasan 1983, 192, pl. 47, figs 6–8.

Remarks: This species is a common element of several samples and sinistral and dextral coiling patterns are approximately equally represented. In sections 11 and 12 the specimens are less heavily thickened than modern *N. pachyderma* specimens from the Antarctic, but other aspects of the species are typical; four sinistral specimens from NPD1985 are typical kummerforms.

Superfamily GLOBIGERINACEA Carpenter, Parker & Jones, 1862
Family GLOBIGERINIDAE Carpenter, Parker & Jones, 1862

***Globigerina apertura* Cushman, 1918** **Pl. 4, fig. 1**

Globigerina apertura Cushman 1918, 57, pl. 12, figs 8a-c: Kennett & Srinivasan 1983, 44, pl. 8, figs 4–6.

***Globigerina bulloides* d'Orbigny, 1826** **Pl. 4, fig. 2**

Globigerina bulloides d'Orbigny 1826, 277, list no. 1; Banner & Blow 1960, 3, pl. 1, figs. 1, 4; Kennett & Srinivasan 1983, 36, pl. 6, figs 4–6.

Remarks: The most common species among the planktonic component. Preservation varies considerably and it is possible that some specimens could be referred to *G. apertura.*

***Globigerina decoraperta* Takayanagi & Saito, 1962**

Globigerina druryi decoraperta Takayanagi & Saito 1962, 85, pl. 28, figs 10a–c.
Globigerina (*Zeaglobigerina*) *decoraperta* Takayanagi & Saito: Kennett & Srinivasan 1983. 48, pl. 9, figs 4–6.

***Globigerina falconensis* Blow, 1959** **Pl. 4, fig. 3**

Globigerina falconensis Blow 1959, 177, pl. 9, figs 40a–c, 41: Kennett & Srinivasan 1983, 40, pl. 7, figs 1–3.

***Globigerina quinqueloba* Natland, 1938**

Globigerina quinqueloba Natland 1938, 149, pl. 6, figs 7a–c: Kennett & Srinivasan 1983, 32, pl. 5, figs 4–6.

Remarks: A few specimens from NPD1985 displaying a great diversity in character of the final chamber. The lip varies from non-existent to well developed, characteristic, according to Kennett & Srinivasan (1983), of the Pliocene. Some specimens have up to 5 ½ chambers in the final whorl.

***Globigerina woodi* Jenkins, 1960** **Pl. 4, fig. 4**

cf. *Globigerina woodi* Jenkins 1960, 352, pl. 2, figs 2a–c: Kennett & Srinivasan 1983, 42, pl. 7, figs 4–6.

Remarks: A single specimen for which apertural details are a little obscured.

***Globigerinoides extremus* Bolli & Bermudez, 1965**

Globigerinoides obliquus extremus Bolli & Bermudez 1965, 139, pl. 1, figs 10–12.
Globigerinoides extremus Bolli: Kennett & Srinivasan 1983, 58, pl. 12, figs 1–3.

***Globigerinoides obliquus* Bolli, 1957** **Pl. 4, figs 5, 6**

Globigerinoides obliqua Bolli 1957, 113, pl. 25, figs 10a–c.
Globigerinoides obliquus Bolli: Kennett & Srinivasan 1983, 56, pl. 11, figs 7–9.

***Globigerinoides quadrilobatus* (d'Orbigny, 1846)** **Pl. 4, fig. 7**

Globigerina quadrilobatus d'Orbigny 1846, 164, pl. 9, figs 7–10.
Globigerinoides quadrilobatus (d'Orbigny): Kennett & Srinivasan 1983, 66, pl. 14, figs 1–3.

***Orbulina suturalis* Brönnimann, 1951** **Pl. 4, fig. 20**

Orbulina suturalis Brönnimann 1951, 135, text-fig. 4, figs 15, 16, 20: Kennett & Srinivasan 1983, 86, pl. 20, figs 1–3.

Remarks: A single specimen in NPD1985, 0.35 mm in diameter. As with *O. universa*, at this size it may be close to its lower temperature limit. Specimens figured by Kennett & Srinivasan (*op. cit.*) are 0.44 and 0.32 mm in diameter.

***Orbulina universa* d'Orbigny, 1839** **Pl. 4, fig. 19**

Orbulina universa d'Orbigny 1839, 3, pl. 1, fig. 1; Kennett & Srinivasan 1983, 86, pl. 20, figs. 4–6; Hornibrook *et al.* 1989, 136, 148, figs 28.2, 31.

Remarks: The occurrence is sporadic and all specimens are very small (~0.35 mm) and at the temperature limit for the species. It thus forms a basis for estimating the palaeotemperature at the time of deposition using the results contained in Bé *et al.* (1973).

Family CANDEINIDAE Cushman, 1927

***Globigerinita uvula* (Ehrenberg, 1861)** **Pl. 4, fig. 21**

Pylodexia uvula Ehrenberg 1861, 206 (figs Ehrenberg 1873, pl. 2, figs 24, 25). *Globigerinita uvula* (Ehrenberg); Kennett & Srinivasan 1983, 224, pl. 56, figs 6–8.

APPENDIX TABLE 1

Distribution of Foraminifera in samples from North Patriarch Drain (1985), and sections S11 and S12. Figures are percentages of the faunas. tr=<1%.

Species/Sample	NPD	S11/1	S11/5	S11/13	S11/13A	S11/14	S11/17	S11/20	S11/22	S11/24	S11/29	S11/31	S11/37	S11/39	S11/40	S11/43	S12/1	S12/2	S12/3	S12/4	S12/7	S12/13	S12/22	S12/24	S12/28	S12.31	S12/32	S12/36	S12/38	S12/prox. Cast. Marl
BENTHIC SPECIES																														
Adelosina sp.												tr																		
Alabamina tenuimarginata																	tr													
Gen. et sp. nov.			tr		tr	tr	tr	tr		tr	tr	tr	tr	2	2	tr	2	2	2	3			2		3	tr	tr	1	1	1
Anomalinoides fasciatus											tr															tr				
Anomalinoides nonionoides	tr																													
Astrononion novozealandicum	tr							tr		tr	tr	tr		?tr		tr				tr	tr	tr	tr					tr	tr	tr
Astrononion obesum					tr		tr									tr												tr		tr
Astrononion tasmaniensis					tr		tr				tr		tr							tr		tr					tr			tr
Baggina philippinensis	tr						tr		tr	tr	tr	tr				tr										tr	tr	tr		
Bolivina pseudoplicata	1.4																													
Brizalina sp.	tr																													
Bulimina cf. *aculeata*	tr										tr					tr	tr							tr					tr	
Cibicides cygnorum						tr																								
Cibicides ihungia					tr				tr		tr	1		1	2	tr	tr		2		tr	1	tr	tr	tr		tr	tr	tr	tr
Cibicides sp. 1	7.5	1	tr	2	5	2	2	tr	3	4	3	3	9		9	8	4	4	7	11	19	10	10	11	11	13	13	10	6	9
Cibicides sp. 2				tr																			tr							
Cibicides thiara	2.2																													
Cushmanina spiralis																												tr		
Dentalina fragment indet.																														
Dentalina godjeni																		tr		tr										1
Dentalina subemaciata				tr														tr							tr					
Discanomalina vermiculata	tr				1																									
Discorbinella araucana																										tr				
Discorbinella bertheloti	tr						tr	tr	tr	tr	tr	tr		tr			tr			tr	tr			tr						tr
Discorbinella cf. *vitrevoluta*	2.8				tr	tr		tr	tr	tr	tr		tr	tr	tr		tr	tr			tr	tr		tr	tr		tr	tr		tr
Discorbinella papillata	1.2											tr		tr					tr					tr						
Discorbinella sp. 1	tr																				tr							tr		tr
Discorbinella timida	3.5	tr			tr	tr																								
Discorbis balcombensis										tr																				
Discorotalia aranea																														tr
Dyocibicdes uniserialis										tr							tr													
Dyocibicides biserialis	tr				tr		tr		tr	tr	tr	tr	tr		tr	tr	tr	tr			tr			tr		tr			tr	tr
Dyocibicides primitiva	1.9	tr			1	tr	tr	tr		tr	2	2	2	4	3	1	6	4	3	3	2	4		1	2	3	8	tr	3	1
Elongobula arethusae	tr																													
Elphidium advenum advenum	9.9		1		5	2	1	tr	1	1	tr	2	3	3	4	5	2	tr	4	5	2	4	3	6	2	2	3	tr	1	2
Elphidium advenum limbatum	tr	1		2	tr	tr	tr	tr	tr									tr	tr					1	tr		tr		tr	tr
Elphidium advenum maorium				tr	tr																									

APPENDIX TABLE 1 cont.

	NPD	S11/1	S11/5	S11/13	S11/13A	S11/14	S11/17	S11/20	S11/22	S11/24	S11/29	S11/31	S11/37	S11/39	S11/40	S11/43	S12/1	S12/2	S12/3	S12/4	S12/7	S12/13	S12/22	S12/24	S12/28	S12.31	S12/32	S12/36	S12/38	S12/prox. Cast. Marl
Elphidium craticulatum	2.8		5	3	tr	4	6	5	2	3	2	tr	1	2		tr	1	tr	tr	tr	tr	tr	tr	1	2	tr	tr	tr	tr	tr
Elphidium crispum crispum		3	8	2	4	1	tr	tr	2	3	tr	3	4	5	5	5	4	tr	3	1	3	2	2	4	2	3	4	2	1	1
Elphidium excavatum clavatum	5.8				tr							tr																		
Elphidium excavatum excavatum	tr	tr		tr				tr																						
Elphidium sp. 1	tr																													
Elphidium tongaense	tr			tr	tr			tr	tr	tr	tr	tr	tr	tr			tr		tr					tr		tr			tr	tr
Entosolenia cf. *lineata*																											1	tr	tr	
Eponides repandus																	tr													
Fissurina lucida	tr								tr						tr															
Fissurina marginata	1.5								tr																					
Fissurina pacifica	tr																													
Fissurina sp. 1	1.4																													
Fissurina sp. 2	tr																													
Fissurina sp. 3					tr																									
Fissurina sp. 4	tr																													
Flintina intermedia	tr																													
Frondicularia juv. sp. indet.																					tr									
Gaudryina convexa	tr																													
Globocassidulina subglobosa	tr																													
Globulina gibba				2	tr			tr	tr						tr				tr											
Gordiospira sp.	tr											tr																		
Guttulina austriaca								tr									tr	tr	tr	tr		tr					tr			tr
Guttulina communis	1.4	tr	tr		2	tr	tr	1	tr	tr	tr	1	tr	tr	tr	tr			tr	tr	tr	tr	tr	tr	tr	tr		tr	tr	
Guttulina lactea	tr																													
Guttulina regina	tr		tr		tr		tr	tr		tr	tr	tr	1	tr	tr	tr	tr		tr	tr	tr	tr	tr	tr	tr	tr	tr			
Guttulina seguenzana	tr			tr																										
Gyroidina neosoldanii																tr														
Heronallenia lingulata	tr	tr			tr		tr				tr			tr		tr	tr				tr	tr							tr	tr
Heronallenia parri										tr		tr																tr		
Heterolepa brevoralis					tr																									
Lagena cf. *maccullochae*																								tr						
Lagena flatulenta								tr										tr												
Lagena maccullochae																											tr			
Lagena perlucida																								tr			tr			
Lagena sp. 1	tr																													
Lagena sp. 2	tr																													
Lagena sp. 3	1																													
Lagena striaospiralata		1																				tr		tr			tr		tr	
Lagena striata paucistriata	1.2																		tr	tr										

APPENDIX TABLE 1 cont.

	NPD	S11/1	S11/5	S11/13	S11/13A	S11/14	S11/17	S11/20	S11/22	S11/24	S11/29	S11/31	S11/37	S11/39	S11/40	S11/43	S12/1	S12/2	S12/3	S12/4	S12/7	S12/13	S12/22	S12/24	S12/28	S12.31	S12/32	S12/36	S12/38	S12/prox. Cast. Marl
Lagena sulcata		tr	tr		1			tr			tr	tr	tr	tr	1	tr		tr	tr	tr	1	tr	tr	tr		1	tr	tr	1	
?Lagena sp.	tr																													
Lamellodiscorbis dimidiatus																													tr	
Laticarinina altocamerata																							tr							
Lenticulina foliata	tr												tr								tr									
Lenticulina indet.										tr																				
Mesorotalia sp.	tr																	tr												tr
Miliolinella subrotunda	2.8	tr					tr		tr	tr	tr																			
Neoconorbina cf.*pacifica*			tr																											
Neoeponides procerus	1.6		tr	tr	tr	tr	tr			tr	tr	tr	tr	tr	tr	tr	tr				tr		tr		tr	2	2	tr	tr	tr
Notorotalia clathrata	3.3	1	4	tr	10	8	8	4	10	8	11	6	7	10	9	9	8	7	12	16	11	7	16	10	13	12	4	10	13	9
Oolina emaciata								tr							tr	1														tr
Oolina globosa	1	1			1	tr		tr		tr		1	2	tr		tr	1		tr			tr		tr		tr	tr	tr	tr	
Oolina hexagona	2.5							tr	tr		tr		tr	tr	2	tr		tr		tr		tr	tr							
Oolina lineata						tr				tr	tr	tr	tr		tr	tr	tr					tr				tr	tr			
Oolina melosquammosa	2.6																													
Oolina ramulosa	tr													tr									tr							
Oolina sp. 1	2.5	tr	tr	tr	tr			tr	tr		tr	tr				1	tr		tr	tr	tr	tr					tr			
Oolina sp.																			tr	tr										
Oolina squamosa		tr							tr	tr	tr	tr	tr		4	1	tr	1	2	2	tr	2	tr	2	tr	1	3	tr	tr	tr
Oolina subacuticostiformis																														tr
Oolina tasmanica					tr												tr													
?Oolina sp.															1															
Palmula longiformis		tr		6																										
Parredicta kalimnensis	6.8	58	69	60	38	62	60	63	38	42	39	32	36	35	28	34	43	45	37	32	30	30	37	41	41	29	35	39	39	54
Parrellina imperatrix		2	tr		tr	tr	tr	tr	tr	tr		tr		1	tr	tr	3	3	tr		tr	tr	tr	1	1	tr	tr	1	tr	4
Parrellina sp.	tr																													
Parrellina verriculata		2	1		6	6	5	4	7	5	6	6	7	8	8		7	7	7	9	7	10		8	7	5	6	6	6	8
Pileolina australensis	tr															tr														
Planodiscorbis sp.								tr																						
Planoglabratella opercularis	tr																													
Planorbulina mediterranensis					tr										tr															
Planulina ariminensis					tr		tr										tr													
Planulinoides biconcavus	tr					tr	tr		tr		tr		tr	tr	tr	tr	tr	tr	tr	tr		tr		tr	tr				tr	tr
Procerolagena clavata	tr																													
Pseudofissurina sp. 1	tr																													
Pseudoflintina crassatina								tr																						
Pseudononion victoriensis	3	6	3		6	1	3	4	8	6	7	8	4	4	4	3	3	3	2	2	2	3	2	3	1	3	6	5	3	tr
Pseudopolymorphina ligua										tr				tr																
Pseudopolymorphina subcylindrica		tr			1	tr	tr	tr	1		2	1			tr	tr	tr	tr	tr	tr	tr	tr	tr	1	tr					tr

APPENDIX TABLE 1 cont.

	NPD	S11/1	S11/5	S11/13	S11/13A	S11/14	S11/17	S11/20	S11/22	S11/24	S11/29	S11/31	S11/37	S11/39	S11/40	S11/43	S12/1	S12/2	S12/3	S12/4	S12/7	S12/13	S12/22	S12/24	S12/28	S12.31	S12/32	S12/36	S12/38	S12/prox. Cast. Marl
Pyrgo sp. 1		tr																												
Pyrgo spp.		tr					tr					tr																		
Pyrulina angusta	tr											tr	2											tr						
Pyrulina fusiformis																tr														
Pyrulina gutta			tr	tr			tr	tr				tr		tr			tr	tr	tr		1	tr		tr		tr	tr		tr	
Quinqueloculina asperula	tr																													
Quinqueloculina lamarckiana									tr		tr	1				1														
Quinqueloculina oblonga								tr	1	3	1	tr			tr	1														
Quinqueloculina seminula	6.5	2	tr	1	1	2	1	1	7	3	3	7	6	3	2	5												1	tr	
Quinqueloculina sp. indet.									tr		tr*																			
Quinqueloculina sp.A	tr																													
?Quinqueloculina poey. victoriensis									tr																					
Rectobolivina sp.	tr																													
Rosalina australis	tr														tr								1							
Rosalina bradyi		tr		tr	tr		tr	tr	tr	tr	tr	tr	tr			tr	tr	tr	tr	tr	tr	tr			tr	tr	tr	tr	tr	tr
Rosalina mitchelli	3				tr																									
Rosalina sp. 1		tr	tr	tr	2	tr	tr		tr		1					tr	tr			tr	tr				tr	tr		1		tr
Rosalina sp. indet.										tr																				
Rosalina sp.3	tr								tr																					
Rosalina vilardeboana	1.6																													
Sigmoidella elegantissima							tr									tr										tr		tr		
Sigmoidella kagaensis		2	3	3	tr	tr	3	2	1	2	2	tr	tr	1		tr	1	2	1		1	2	tr	2	tr	tr	tr	2	1	tr
Sigmomorphina cf. *schwageri*													tr																	
Siphotextularia cf *saulcyana*	tr																													
Siphotextularia saulcyana	tr																													
Sphaerogypsina globulus														tr																
Spiroloculina canaliculata											tr																			
Textularia candeiana				tr																										
Trifarina cf. *bradyi*	tr																													
Triloculina earlandi	1.2				tr		tr		1	tr		tr	tr	tr		tr cf														
Triloculina gilboei		tr					tr			tr	1	tr		tr															tr	
Triloculina laevigata		2		1		tr		2	tr					tr																
Triloculina tricarinata		tr		tr		tr	tr	tr	tr	tr		tr				tr														
Triloculina trigonula	tr	4		3	tr	1	2	2	6	6	5	5	2	2	1	3												2	4	
Unident. nodosariids	tr																													
Unident. miliolids	1.6									3		1	2	tr		3														
Unidentified		tr		2	3	2	2	1	1	2	tr	4	5	7	7	1	11	9	12	9	11	15	8	15	7	15	7	8	10	4
Uvigerina pliozea	1.2										tr	tr	tr			1			tr		tr	tr	tr	tr	tr		tr	tr	tr	tr

APPENDIX TABLE 1 cont.

	NPD	S11/1	S11/5	S11/13	S11/13A	S11/14	S11/17	S11/20	S11/22	S11/24	S11/29	S11/31	S11/37	S11/39	S11/40	S11/43	S12/1	S12/2	S12/3	S12/4	S12/7	S12/13	S12/22	S12/24	S12/28	S12.31	S12/32	S12/36	S12/38	S12/prox. Cast. Marl
Uvigerina rodleyi		tr		tr	tr			tr	tr	tr																				
Vaginulina vertebralis	tr													tr				tr												
Virgulopsis sp.	tr																													
TOTAL BENTHICS	**429**	**459**	**569**	**476**	**484**	**842**	**732**	**574**	**416**	**792**	**627**	**494**	**252**	**338**	**261**	**295**	**518**	**310**	**528**	**420**	**449**	**576**	**378**	**518**	**335**	**249**	**472**	**466**	**598**	**625**
PLANKTONIC SPECIES																														
Globigerina apertura					1			2	1																1			1		1
Globigerina bulloides	83	2		2		2		4	4	7	10	8	1	4	1	1	14	4	4	14	7	5	2	12	1	1	9	7	5	10
Globigerina cf woodi					1																									
Globigerina decoraperta	2																													
Globigerina falconensis				1		1	1			1											1			1						
Globigerina quinqueloba	9																													
Globigerinita uvula	3			1																										
Globigerinoides extremus				1	1																									
Globigerinoides obliquus																	1													
Globigerinoides quadrilobatus								1																						
Globorotalia crassaformis	30				1			1	2		2			1			1		1			1	1	1					1
Neogloboquadrina humerosa	1				1									1		1														
Globorotalia intern. *inflata/ puncticulata*												1																		
Globorotalia mons																	1										1			
Globorotalia 'obesa'	44																													
Globorotalia pliozea	1							1						1			cf. 1		1	1			1							
Globorotalia puncticulata										2		3			1					3	2								1	1
Neogloboquadrina pachyderma	4s	cf. 1d		1s	1d			1s;2d	1s;1d	2d	2s;2d	5s	1s								3s		1s	1s						
Orbulina universa												3		2	1			1									1	1		
Orbulina suturalis	1																													
Unidentified		2		1	2	2	1	3		3	9	5	1			2					3								1	

ERRATUM

Fitzgerald, N.B. & Whinam, J. 2012 (14:xii) Establishing a monitoring program for Tasmania's montane conifers. *Papers and Proceedings of the Royal Society of Tasmania* 146: 9–24.

The captions to plates 1–4 are mislabelled. The plates and correct captions are as follows:

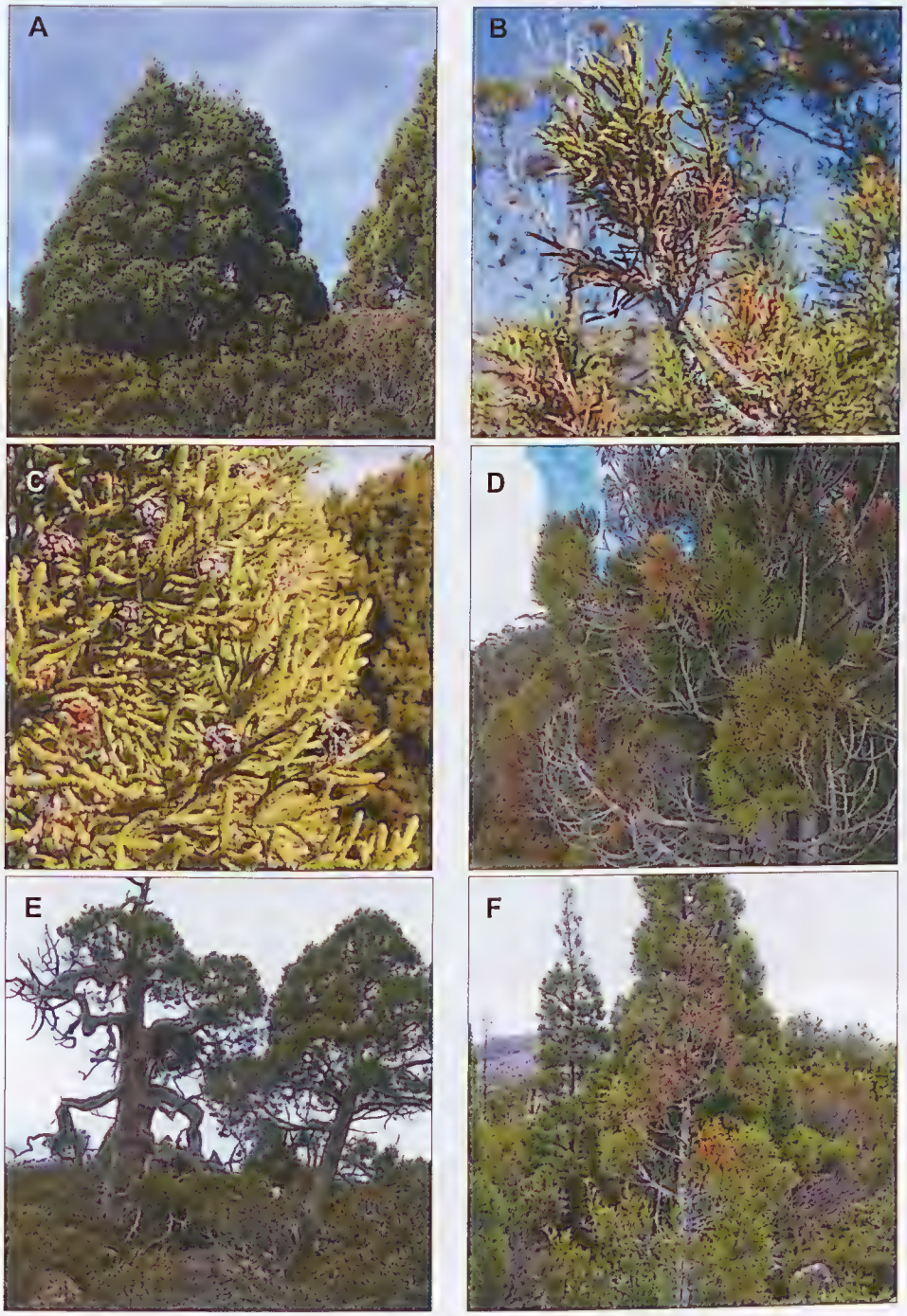

PLATE 1
Examples of Pencil Pine, Arthrotaxis cupressoides, *condition classes: (A), (C) = 4; (E), (B) = 3; (D), (F) = 2.*

PLATE 2
Examples of King Billy Pine, Athrotaxis selaginoides, *condition classes: (A), (C) = 4; (E), (B) = 3; (D), (F) = 2.*

PLATE 3
Examples of Dwarf Pine, Diselma archeri, *condition classes: (A), (C) = 4; (E), (B) = 3; (D), (F) = 2.*

PLATE 4
Examples of Drooping Pine, Pherosphaera hookeriana, *condition classes: (A), (C) = 4; (E), w(wB) = 3; (D), (F) = 2.*

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Book:

Davison, A. C. & Hinkley, D. V. 1997: *Bootstrap Methods and their Application.* Cambridge University Press, Cambridge: 592 pp.

Edited work:

Marchant, S. & Higgins, P. J. (eds) 1993: *Handbook of Australian, New Zealand and Antarctic Birds. Volume 2: Raptors to Lapwings.* Oxford University Press, Melbourne, Australia: 1048 pp.

Chapter in an edited work:

Artyukhin, Y. B. & Burkanov, V. N. 2000: Incidental mortality of seabirds in the drift net salmon fishery by Japanese vessels in the Russian Exclusive Economic Zone, 1993–1997. *In* Kondratyev, A. Y., Litvineko, N. M. & Kaiser, G. W. (eds): *Seabirds of the Russian Far East.* Ottawa, Canadian Wildlife Service Special publication: 105–116.

Thesis:

Charleton, K. J. 2002: Variation in Sooty Shearwater burrow entrance density, burrow use and chick emergence: Science and Traditional Environmental Knowledge approaches. Unpublished MSc thesis, University of Otago, Dunedin.

Electronic version of journal:

Chiswell, S. M. & Rickard, G. J. 2006: Comparison of model and observational ocean circulation climatologies for the New Zealand region. *Journal of Geophysical Research* **111**: C10011, doi:10.1029/2006JC003489.

Website:

IUCN 2001: *IUCN Red List of Threatened Species 2001 Categories & Criteria (version 3.1)*, www.iucnredlist.org (accessed 22 January 2007).

Report:

MacKenzie, D.I. & Fletcher, D. 2005: Characterisation of seabird captures in NZ fisheries. Report to Ministry of Fisheries for Project ENV2004-04. April 2006. Unpublished Report to the Ministry of Fisheries, Wellington: 99 pp.

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